ERDC/CRREL TR-08-22

Cold Regions Research and Engineering Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Opportune Landing Site Program

Opportune Landing Site Southeastern Indiana Field Data Collection and Assessment

Lynette A. Barna, Charles C. Ryerson, and Rosa T. Affleck

November 2008

ERDC/CRREL TR-08-22
November 2008

Opportune Landing Site Southeastern Indiana Field Data Collection and Assessment

Lynette A. Barna, Charles C. Ryerson, and Rosa T. Affleck

Cold Regions Research and Engineering Laboratory
U.S. Army Engineer Research and Development Center
72 Lyme Road
Hanover, NH 03755-1290

Final report

Approved for public release; distribution is unlimited.

Prepared for U.S. Air Force Research Laboratory Air Vehicles Directorate

Under Customer Order Number GWRVA0047212

Abstract: Effectiveness in modern warfare demands rapid, lethal, and stealthy response to a wide variety of adversaries. This requires, in part, the ability to conduct air transport operations to locations where there are no existing runways, and where engineers cannot be prepositioned. One of the most difficult problems is locating large, smooth, flat, and obstruction-free areas that are also sufficiently firm to support at least one aircraft operation, and preferably, many. The opportune landing site (OLS) program utilized existing technologies to rapidly accelerate the process of selecting OLSs using remote sensing technology and state-of-the-ground forecast tools. To evaluate the quality of the OLSs identified, ground truth activities were conducted at four field locations. Two of these sites, described in this report, were located in rural, actively farmed areas in southeastern Indiana. Field measurements were made during four seasons to assess the smoothness, flatness, freedom from obstructions, and, most importantly, the soil strength. The procedures and tools used to assess the candidate OLSs were, to the extent practical, based on established practice for evaluating paved and contingency airfields. The results from the Indiana field activities and the success of the procedures used in assessing the suitability of the OLSs are presented.

Contents

Figures and Tables

Figures

Tables

Preface

This report was prepared by Lynette A. Barna and Rosa T. Affleck, both Research Civil Engineers in the Force Projection and Sustainment Branch (FPSB), and Dr. Charles C. Ryerson, Research Physical Scientist in the Terrestrial and Cryospheric Sciences Branch (TCSB), U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH. The authors acknowledge the following organizations and individuals for their generous support and cooperation in providing areas to conduct seasonal ground truth operations: North Vernon Municipal Airport Committee; Ryan Curry, Director of Airport Operations, North Vernon Municipal Airport, North Vernon; Mr. and Mrs. Dean Ford, Dupont; and Donald Biehle, Manager, Southeastern Purdue Agricultural Center, Butlerville. ERDC-CRREL technical support was provided by Christopher Berini, Gordon Gooch, Tom Hall, Elke Ochs, Keran Claffey, Bruce Elder, Sherri Orchino, Charlie Smith, Eric Phetteplace, Kevin Bjella, Andrew Stanley, and Joni Quimby. The authors also express sincere appreciation to Wendy Wieder for assistance in preparing the final report. The authors also express their appreciation to Dr. Ron Meade, Pensacola, FL, and Dr. Sally Shoop and Deborah Diemand of ERDC-CRREL for the thoughtful and thorough technical review of this report.

This report is a deliverable product in support of customer order number GWRVA0047212, “Opportune Landing System,” conducted in collaboration with Boeing, the Air Force Research Laboratory (AFRL), and Syngenics Corporation. Dr. Charles C. Ryerson was Program Manager at ERDC/CRREL, and James McDowell, AFRL, Air Vehicles Directorate (AFRL/RB), Wright-Patterson Air Force Base (AFB), was overall Program Manager.

Funding for this work was provided by the U.S. Transportation Command (TRANSCOM) through the Air Force Mobility Command (AMC), Scott AFB, Illinois, and the AFRL/VA, Wright Patterson AFB, Dayton, OH.

The report was prepared under the general supervision of Dr. Bradley Guay, Chief, FPSB, ERDC-CRREL; Dr. Justin Berman, Chief, Research and Engineering Division, ERDC-CRREL; and Dr. Robert E. Davis, Director, ERDC-CRREL. COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
millimeters	3.93701×10^{-2}	inches
centimeters	3.93701×10^{-1}	inches
meters	3.28084	feet
meters	1.09361	yards
kilometers	6.21371×10^{-1}	miles (statute)
square millimeters	1.55000×10^{-3}	square inches
square meters	1.07639×10^{1}	square feet
square meters	1.19599	square yards
milliliters	3.38140×10^{-2}	fluid ounces
liters	2.64172×10^{-1}	gallons
cubic meters	3.53147×10^{1}	cubic feet
cubic meters	1.30795	cubic yards
kilograms	2.20462	pound-mass, avoirdupois (avdp)
grams	3.52740×10^{-2}	ounces (avdp)
kilograms per cubic meter	1.68555	pound-mass (avdp) per cubic yard
kilograms per cubic meter	6.24280×10^{-2}	pound-mass (avdp) per cubic foot
degrees Centigrade	$1.8 \times (°C) + 32$	degrees Fahrenheit
megapascals	1.45038×10^{2}	pound-force per square inch

Nomenclature

AFCESA	Air Force Civil Engineer Support Agency
AFRL/RB	Air Force Research Laboratory, Air Vehicles Directorate
AGL	Allowable gross load
AMC	Air Mobility Command
ATT	Advanced theater transport
AWOS	Automated weather observing system
BGSU	Bowling Green State University
BLSI	Boeing landing stability index
CBR	California bearing ratio
CONUS	Contiguous United States
CORS	Continuously operated reference stations
CRREL	Cold Regions Research and Engineering Laboratory
DCP	Dynamic cone penetrometer
DoD	Department of Defense
ERDC	Engineer Research & Development Center
FCS	Future combat systems
GIS	Geographic information system
GPS	Global positioning system
IV	Impact value
IOP	Intensive operational period
LZ	Landing zone
MS	Multispectral
MUTC	Muscatatuck Urban Training Center
NRCS	Natural Resources Conservation Service
OLS	Opportune landing site
RAS	Runway assessment site
SAS	Soil assessment site
SEPAC	Southeastern Purdue Agricultural Center
SSTOL	Super-short takeoff and landing
TRANSCOMM	U.S. Transportation Command
USACE	U.S. Army Corps of Engineers
USCS	Unified Soil Classification System
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WAAS	Wide Area Augmentation System

1 Introduction

Effectiveness in modern warfare requires rapid, lethal, and often times, stealthy response to a wide variety of adversaries, relying upon agility and speed as components of operating philosophy. This requires, in part, the ability to conduct air transport operations to locations where there are no existing runways, and where engineers cannot be prepositioned because of time constraints and the need for surprise. In 2006, the U.S. Department of Defense (DoD) issued a future vision to position the U.S. military for both current and future conflicts (Department of Defense 2006). Among the report's observations was a need for the capability of a rapid response, deployable within hours, not weeks, with a global reach including delivery of cargo and equipment to austere locations. This involves landing on semi-improved or austere airfields.

One of the most difficult problems is locating large, smooth, flat, and obstruction-free areas that are also sufficiently firm to support at least one aircraft operation, and preferably many. Today, locating an adequate opportune landing site (OLS), as these areas are called, requires skilled image analysts and days of work, augmented by site survey teams visiting candidate locations and assessing the proposed site or landing zone (LZ).

Several new approaches have been taken to improve the capability of rapidly locating OLSs from the use of satellite imagery (Vincent and Jennings 2004; Ryerson and McDowell 2007). Using the approaches described by these authors, the OLS program is demonstrating and improving upon the capability of current technology for locating satisfactory sites, with the future goal of landing airplanes without first placing “boots on the ground.” Initial concepts developed at Bowling Green State University (BGSU) were used by The Boeing Company to demonstrate that potential suitable locations could be identified to conduct operations with transport aircraft. The Boeing Company made the case that the need exists to exploit the advantages provided by the versatility of intratheater maneuverability (McMichael 2007).

Using 30-m resolution Landsat imagery, Dr. Robert Vincent from BGSU developed techniques using five of the Landsat bands to exclude areas of dense, woody vegetation, standing water, sloping and undulating ground,

and obstructions (Manley 2001; Vincent and Jennings 2004). Landsat pixels were provided with a score, the Boeing Landing Suitability Index (BLSI) indicating the relative quality of a pixel for landing aircraft. Smaller BLSI numbers related to higher quality surfaces. When adjacent pixels with BLSI numbers less than a set threshold value equating to an acceptable surface were combined to form a contiguous surface of minimum specified size and direction, an OLS was plotted on the Landsat image.

Boeing and BGSU evaluated the site location module of the OLS software, designated OLS-Multi-Spectral (MS), at a number of field sites (Alvin 2000; Manley 2001; Vincent and Jennings 2004) in California, New Mexico, South Dakota, and Louisiana, and found that the software did locate sites with the attributes sought. In addition, all sites were judged firm enough to support aircraft. So, even though an explicit methodology was not created in the software to locate firm locations, OLSs located were, fortuitously, firm.

1.2 Program scope

The OLS program, managed by the air vehicles directorate at the Air Force Research Laboratory (AFRL/RB) at Wright-Patterson Air Force Base, in partnership with the U.S. Army Corps of Engineers Engineer Research and Development Center (USACE-ERDC) and The Boeing Company, was intended to demonstrate how existing technologies can rapidly accelerate the process of selecting OLSs using remote sensing technology and state-of-the-ground forecast tools (Ryerson and McDowell 2007). Additionally, during the demonstration process, techniques within the program were improved and made more robust.

The ERDC OLS program had three goals. One goal was to evaluate the ability of the Boeing OLS-MS software to locate smooth, flat, level, and obstruction-free areas for landing zones using multispectral Landsat imagery. This was accomplished by locating software-selected OLSs in the field and quantifying their landing zone characteristics.

The second goal was to evaluate the capability of the OLS-MS software to locate OLSs in any season. This involved two concepts. One concept dictated using an image taken during one season at a location, and determining if the OLS(s) found during that initial season was valid for all seasons. The second concept involved evaluating the ability of the software to locate OLSs on images taken each season. The software may have a seasonal

preference, and could fail to locate OLSs properly during some seasons, and succeed in others.

The third goal was to evaluate the OLS-MS software for its perceived ability to locate firm landing zones because Boeing found an association between selected OLSs and soil firmness in early field verifications of the software. To ensure that potential landing zones selected by the OLS-MS software are sufficiently firm to support an aircraft, inferences of soil strength are made in another module of the OLS software, separate from the runway selection, using techniques available from Boeing and ERDC. Because there is a relationship between soil moisture, soil type, and soil strength, multispectral methods were used to determine soil type, and weather forecasting methods were used to predict soil moisture. Soil strength relationships derived from soil type and soil moisture were made more robust using data collected in the field.

The OLS program, started in mid-2004 and scheduled for completion in September 2007, consisted of eight fundamental tasks. Boeing (1) provided software allowing the selection of OLS locations using satellite imagery, (2) provided a capability of predicting soil type, (3) provided a military utility study, and (4) intended to integrate products from all partners into a coherent software package. ERDC (5) evaluated the capability of Boeing OLS software for reliably locating suitable OLSs, (6) provided the capability to predict soil moisture with depth, and (7) provided the capability of inferring soil strength. The capability of all partners was evaluated (8) in a blind test during 2007. Although the end state in 2007 did not yield a full operational capability, it demonstrated the capabilities of current technology.

This report describes work addressing ERDC task 5, and portions of tasks 6 and 7 described above. This was accomplished by conducting field work at locations within the contiguous United States (CONUS) selected by the Boeing OLS-MS software according to criteria described in Section 2 of this report. Specifically, ERDC's goals were to establish whether OLSs selected by the software were suitable to support operations by military aircraft. For the purposes of this study, existing criteria used to evaluate both paved and contingency airfields were applied to assess the software-selected OLSs. These established criteria were created jointly by the Air Force and the USACE, and provided the requirements for both paved and

unpaved runways regarding suitability for various types of aircraft, loadings, and number of operations (Air Force 2002).

Additionally, the field work was used to gather data on soils (i.e. density, moisture content, strength measurements) that will be used to populate the OLS soils database being used to formulate models for soil strength inference. A goal in this effort was to provide data for as many soil types as practical to provide the OLS program with a comprehensive soils database.

Ultimately, ERDC conducted extensive field work at four locations where OLSs were identified: El Centro Naval Air Facility (Affleck et al. 2008a) in southern California, Ft. Bliss in New Mexico (Affleck et al. 2008b), and two locations in southern Indiana. Four additional non-OLS sites in southern Indiana were evaluated less extensively and are also discussed in this report. This report describes field work conducted at the sites located in southern Indiana, and provides a seasonal assessment of the suitability of the software-selected OLSs for potential use as a viable landing site.

2 Site Selection

The Air Force includes the following siting considerations when selecting an airfield location: topography, vegetative cover, existing construction, weather elements, wind direction, soil conditions, flood hazard, natural and man-made obstructions, adjacent land use, availability of usable airspace, accessibility of roads and utilities, and potential for expansion. The potential for encroachment and effects of noise on the local community are also considered (Air Force 2004). The OLS-MS software is not yet designed to take into account all of the criteria considered by the Air Force, and all of the criteria are not necessarily applicable to austere airfields that will have limited aircraft operations. Currently, the OLS program is designed to select locations that are smooth, flat, level, and free of both obstructions and woody vegetation that would harm aircraft. Therefore, the OLS characteristics were only evaluated based on what the software can be expected to predict.

This study used two types of field sites from the OLS program: runway analysis site (RAS) and soil analysis site (SAS). RASs consisted of entire OLS runways located by the Boeing OLS-MS software and selected for detailed analysis by ERDC. Two RASs were selected for full evaluation in southeastern Indiana and, to compare the effects of seasonal change, were revisited over the course of four seasons. The required minimum landing zone length is 914 m for a C-130, and 1,067 m for a C-17 (Air Force 2004). Even though southeastern Indiana is a rural area, the OLS-MS software was unable to locate runways of these lengths because of natural or man-made boundaries, such as tree lines or roads, typically demarcating property lines. Therefore, an RAS represents a landing site with the dimensions of 20 m by 600 m, or longer.

SASs are smaller sites, inadequately sized for runway use, and are selected for the soil types present. The purpose of the SAS sites is to broaden the range of soils investigated in this study by providing additional soil types present in the same geographic area, yet specifically not located on an RAS. The soil types sampled at the SAS locations were intended to be different than those at the RAS locations. The seasonal testing of SAS soils also provides additional data on seasonal changes to soil properties such as moisture content and strength. The data from the SAS soils are being

used to develop soil moisture and soil strength algorithms within the OLS program. The SAS locations were not evaluated as comprehensively as the RAS locations, however, the same field measurement techniques were used at the SAS locations.

The Boeing OLS-MS software version 7 (dated March 27, 2005) was executed using a Landsat 5 scene from March 17, 2005, path 20, row 33. A flatness index of 0.02, a constant value recommended by Boeing, was used for the analysis. The vegetation index was varied from 1.6 to 1.8. The area of interest in southeastern Indiana was narrowed to the vicinity near Jefferson Proving Ground. Figure 2-1 shows the results from the software run.

The output from the OLS-MS software includes the OLS number, end-point coordinates in Universal Transverse Mercator (UTM) geographic coordinate system, direction, and length. The results from the software were mapped over a U.S. Geological Survey (USGS) uniform-scale photographic map, orthophotoquad, to provide major landmarks, as shown in Figure 2-1. Sixteen groups of OLSs were identified within the area of interest. Clusters of numerous (often overlapping) OLSs were identified within these groups as shown in Figure 2-1.

During an initial visit to the area in early April 2005 (Appendix A), brief visual assessments were made of OLSs in all but two of the groups to select a suitable OLS for detailed field evaluation. OLSs were assessed in Areas 1–13 and 16; OLSs in Areas 14 and 15 were not assessed. To accomplish the assessment, the OLSs in each area were overlaid on 5-m resolution orthophoto imagery (USGS Digital Orthophotos 2007) from the late 1990s. The orthophoto imagery, when used in conjunction with local maps, was essential in locating the areas on the ground. The OLS end-point coordinates were identified on the ground using a handheld global positioning system (GPS) equipped with Wide Area Augmentation System (WAAS).

The brief visual assessment provided a general evaluation to determine if the OLSs met the criteria and were large, smooth, flat, level, and obstruction free. Overall, when viewing the OLSs identified by the software on the ground, they were in locations that appeared flat, smooth, and level. There were, however, cases where the software failed to identify obstructions that would impede aircraft operations, such as drainage ditches, power poles, and paved roads. Table 2-1 summarizes the visual observations

made during the initial visit for the areas assessed. An example of an OLS that intersected all three of these obstacles was located in Area 10 (Fig. 2-2, a and b). The orthophoto in Figure 2-2a, shows OLSs 229, 231, and 4207 crossing a paved road. The photograph in Figure 2-2b shows the view on the ground where the paved road crosses the three OLSs. Running along the northern edge of the road is also a utility line and a drainage

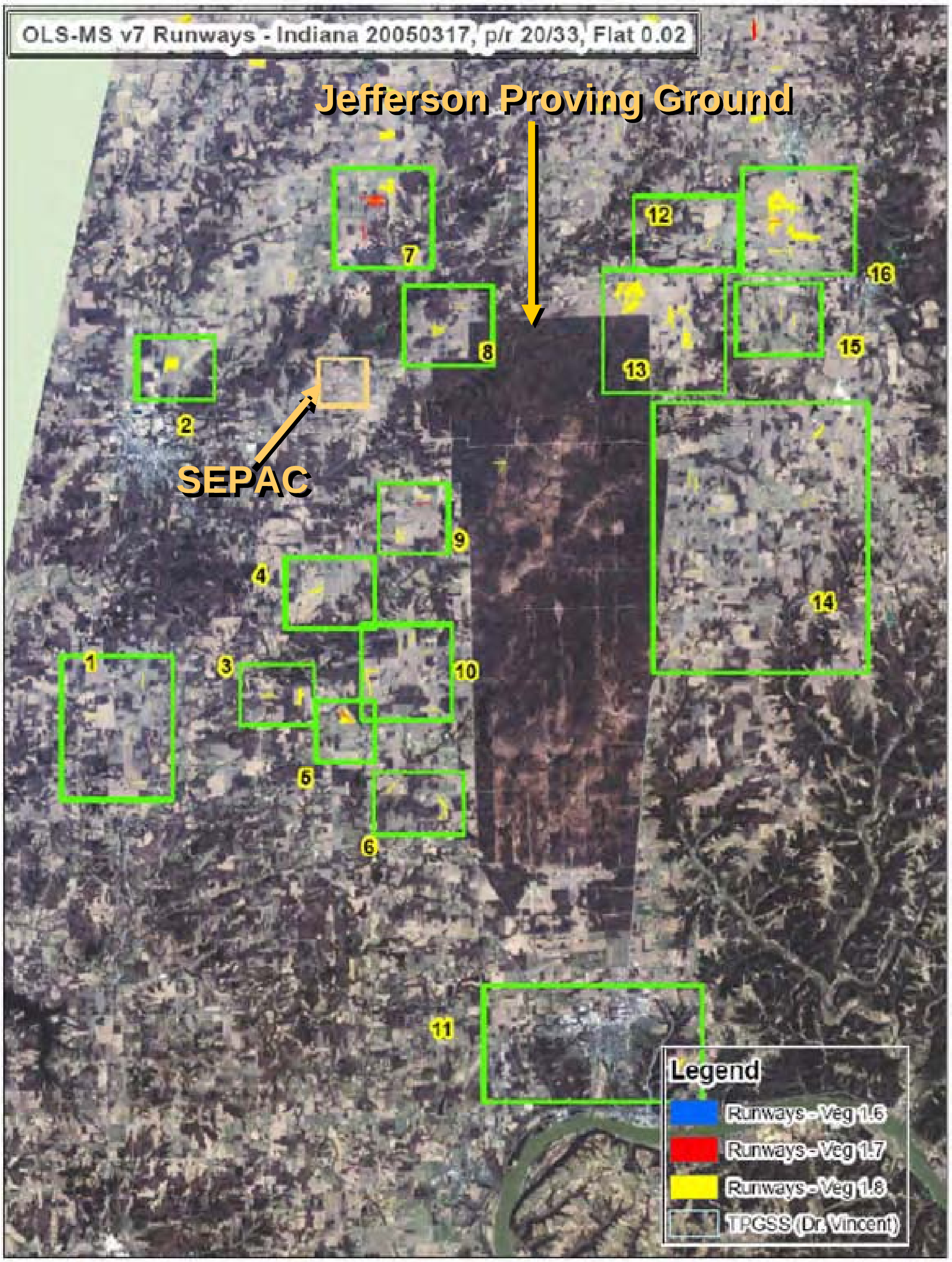


Figure 2-1. Software-identified OLS locations (in green boxes) in southeastern Indiana.

ditch. None of these obstructions were recognized by the software, and none met the obstruction-free criteria.

In this study, the two most important factors for selecting suitable OLSs for field evaluation were access to the site and logistics to conduct the field work. The cluster of OLSs in Area 2 was of interest given the large number identified by the software and proximity from the road. The land in this area is owned and managed by the city of North Vernon, including the area across the road where North Vernon Municipal Airport is located. Figure 2-3 shows the cluster of OLSs near the North Vernon airport that were assessed. This field is actively farmed with the primary crops of either corn or soybeans. At the time of the initial visit in early April 2005, surface water indicated that the field was wet. In general, the field was flat and free of obstructions (Fig. 2-4), however, for OLSs oriented in a north-south direction, there was a drainage ditch (approximately 3-m wide and 1-m deep) that cut across the field in an east-west direction. An OLS was selected for detailed evaluation in the southern portion of this field, parallel to the obstructive drainage ditch, and oriented in an east-west direction. This site will be referred to in this report as the North Vernon Airport RAS.

Two OLSs in the northwestern corner of Area 6 were also assessed (Fig. 2-5). They were closely parallel to each other and oriented in a northeast-southwest direction. In addition, they were generally flat and obstruction free, and the diagonal orientation was of interest in selecting this OLS for field operations. This location was at the Dean Ford Farm (Fig. 2-6), and the OLS site selected for evaluation will be referred to as the Ford Farm RAS in this report.

The four SAS locations are shown in Figures 2-7, a and b. These locations were chosen at the request of AFRL (Haren 2005) and were in proximity to the RASs to reduce travel time between the sites. SASs were selected less rigorously than RASs because they did not have to meet all the criteria for use as an OLS (i.e., minimum landing length). All of the SAS locations were in Butlerville, IN. Three of the SASs selected for evaluation were located at the Southeastern Purdue Agricultural Center (SEPAC) (Fig. 2-1,) and one SAS was located nearby at Indiana National Guard, Muscatatuck Urban Training Center (MUTC). The SAS sites will be designated by their soil types in this report. The Cobbsfork, Cincinnati, and Wilbur SAS sites were all located at SEPAC, whereas the Parke SAS was located on adjacent MUTC property.

Table 2-1. Summary of visual observations of OLSs during initial field visit in southeastern Indiana.

Area	OLS Number	Description	Large	Smooth	Flat	Obstruction-free	Comments
2		OLS cluster	Y	Y	Y	A drainage ditch crosses OLSs oriented north-south. OLSs oriented east-west appear to be obstruction-free.	This site was selected for detailed evaluation.
4	115	OLS cluster	Y	OLS is located in a corn field that crosses hilly terrain.		Crosses a drainage ditch that is 10- to 15-m wide and several meters deep.	
4	2095 2096 3094		Y	Y	Y	Y	
4	131 1412		Y	Y	Y	Cross a road.	
5	3111		Y	Y	Y	From a distance, ditches and ponded water were observed. May not have been on the OLS.	
5		Large cluster	Y	Y	Y	Previous crop appeared to be soybeans, leaving less vegetation surface debris. OLSs oriented east-west appear to be obstruction-free. OLSs oriented north-south or northwest-southeast cross a dirt road with a parallel utility line.	
6	1458 1459	Western side	Y	Y	Y	Y	OLSs orientation misses hills, valleys, and other obstructions. This site was selected for detailed evaluation.
7	1373 1375 3663 2557 others	OLS cluster	Y	Y	Y	Y - notably the OLSs are oriented and miss large barn.	Potential candidate OLSs.
10	292		Y	Y - with corrugations from farming activities.		Crossed a paved road with utility line and drainage ditches running parallel on either side of road	
10	335 1429 1430 2099 3095		Y	Y	Y	Fields observed from roadside. Cornstalk stubble on surface from previous crop. Fields were wet.	Potential candidate OLSs.

Table 2-1 (cont'd). Summary of visual observations of OLSs during initial field visit in southeastern Indiana.

Area	OLS Number	Description	Large	Smooth	Flat	Obstruction-free	Comments
12	460 461		Y	OLSs located on hilly terrain.		OLSs cross a road.	
16	819 4091 3636 3051 3052 3053	Southern end	Y	Y	Y	OLS 3053 crosses a road. The other OLSs appear to be obstruction-free.	
16		OLS cluster	Y	Y	Y	Some surface water in fields, but largely obstruction-free. Exception is OLS 3053 that crosses a road.	
16		OLS cluster in northern section	Y	Y	Y	A road cuts across the western end of the cluster. Many OLSs appear to be either north or south of the road and look obstruction-free. OLSs oriented east-west cross the road.	

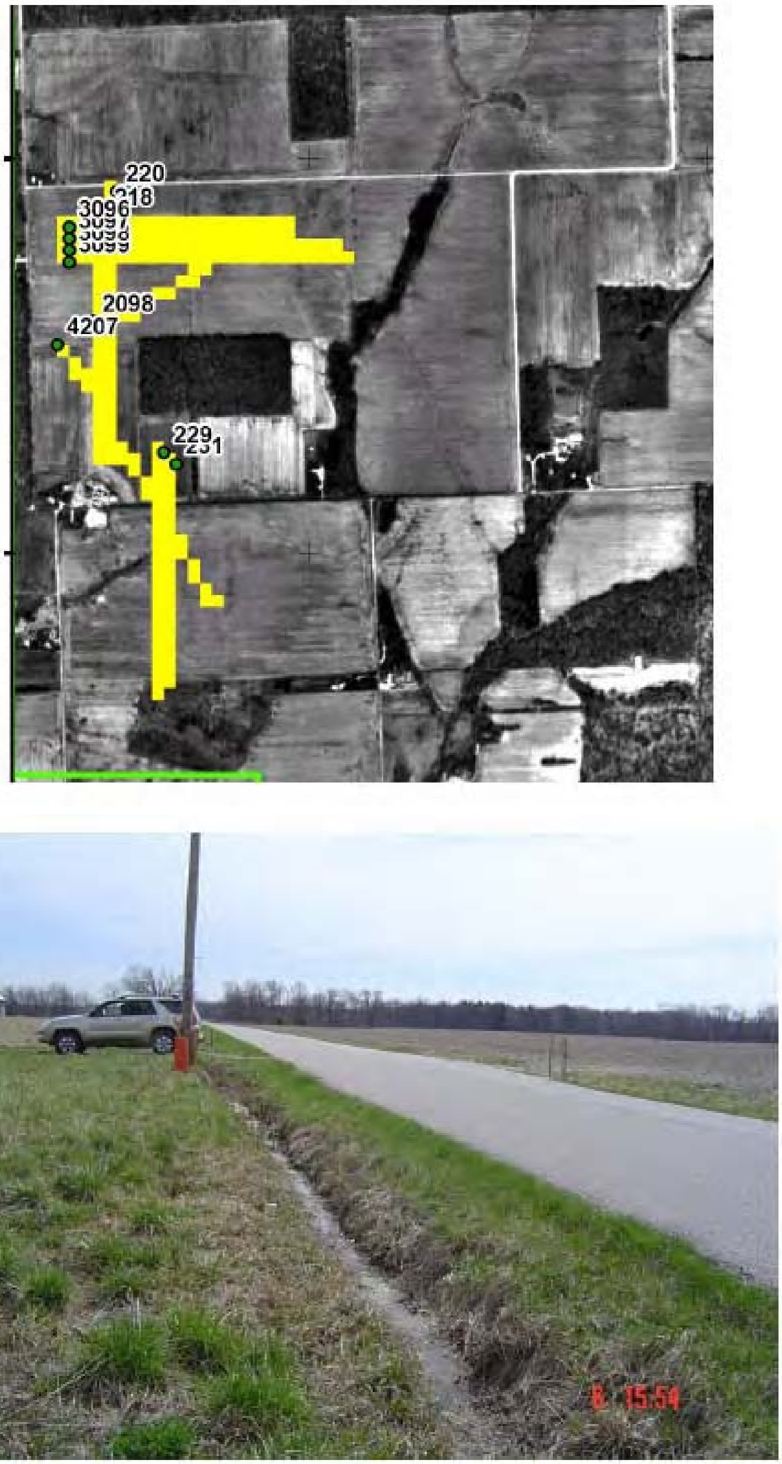


Figure 2-2. OLSs 229, 231, and 4207 with obstructions. (Top) OLSs 229, 231, and 4207 with obstructions as seen on the image. (Bottom) OLS 229, 231, and 4207 as seen at ground level showing obstructions of paved road, utility line, and drainage ditch.

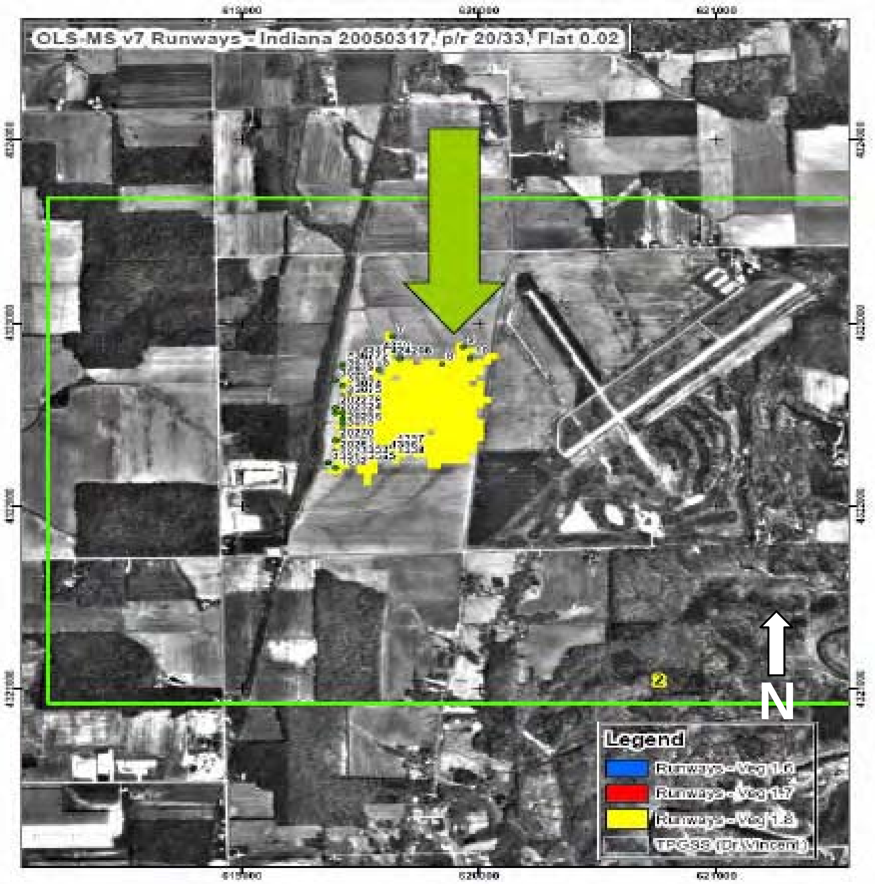


Figure 2-3. Cluster of OLSs in Area 2, near North Vernon Municipal Airport.

Figure 2-4. Field in Area 2 containing OLS cluster near North Vernon Municipal Airport as viewed from the road.

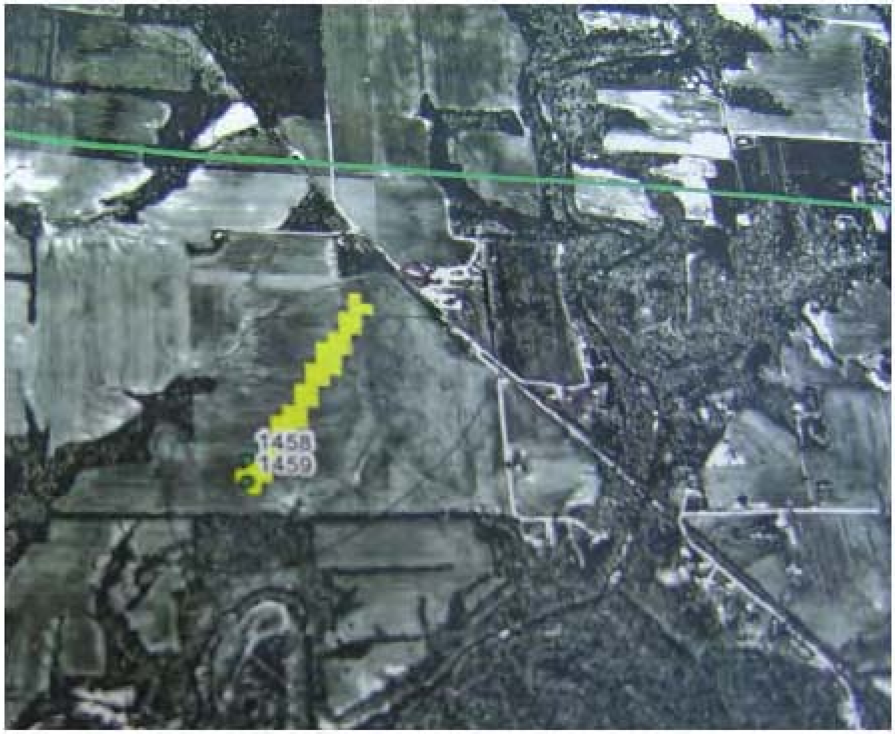
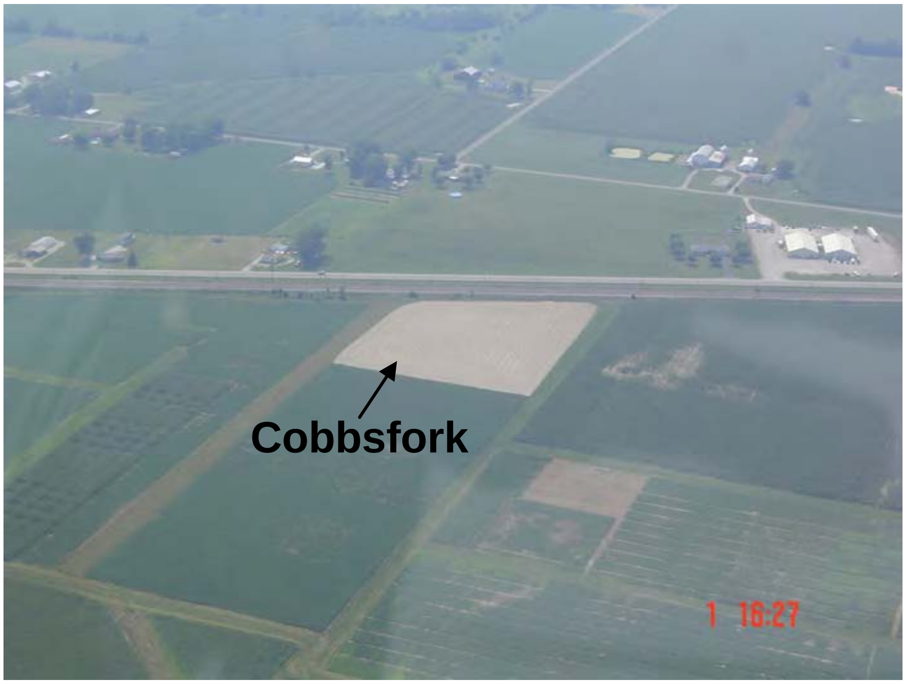
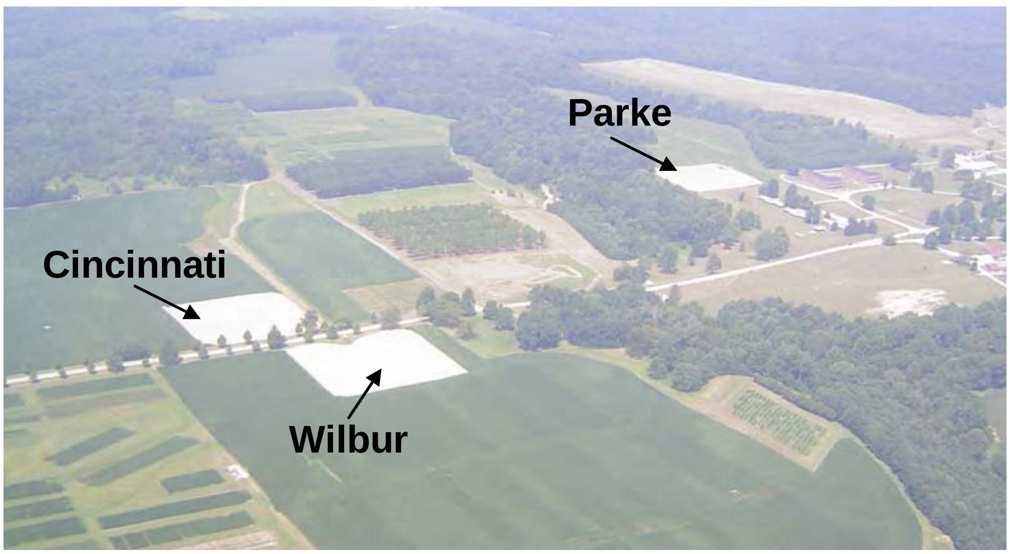


Figure 2-5. Diagonal and parallel OLSs in northwestern corner of Area 6.

Figure 2-6. Near the end points of OLSs 1458 and 1459 located at the Ford Farm.



2-7a. Aerial view of SAS Cobbsfork at SEPAC.



2-7b. Aerial views of SAS Cincinnati and Wilbur at SEPAC, and Parke at MUTC.

Figure 2-7. Indiana SAS sites.

3 Acceptance Criteria for Runway and Soil Assessment Sites

To determine if the OLS-MS software identified suitable landing sites that met dimensional and strength requirements, a field program was created to "ground truth," or assess, the adequacy of the RASs. Currently, no standard method of evaluating an RAS exists and, for this reason, the dimensional requirements published in ETL 04-7 (Air Force 2004) and the evaluation procedures in ETL 2002-19 (Air Force 2002) and FM5-430-00-2/AFJPAM 32-8013 (Headquarters Departments of the Army and Air Force 1994) provided the basis for a detailed assessment. The chart in Figure 3-1 describes the major features considered in determining the suitability of an RAS. Other standard industry practices, such as ASTM standards, relating to vehicle mobility and pavement engineering were used where applicable. For the purpose of this study, Figure 3-1 was adapted from the Air Force pavement evaluation method for unsurfaced airfields (Air Force 2002). Each step of the process is described in more detail. Although not evaluated as comprehensively as the RAS locations, the same field measurement techniques were used at the SAS locations.

In addition, the seasonal component of the work involved several field visits to each site. The season and corresponding field testing dates for all intensive operational periods (IOPs) for both RAS and SAS sites are listed in Table 3-1.

Field testing during the spring IOP1 occurred shortly after the initial April 2005 site visit. Subsequent field tests were conducted during the summer, fall, and winter seasons to capture changes to the RAS that may be due to both the seasonal influences and impacts from farming.

Table 3-1. IOP date listing.

Purpose	Season	Dates	IOP
Initial site visit		5–7 April 2005	—
Field visit	Spring	18—22 April 2005	IOP1
Field visit	Summer	1—5 August 2005	IOP2
Field visit	Fall	30 October—4 November 2005	IOP3
Field visit	Winter	27 February—3 March 2006	IOP4

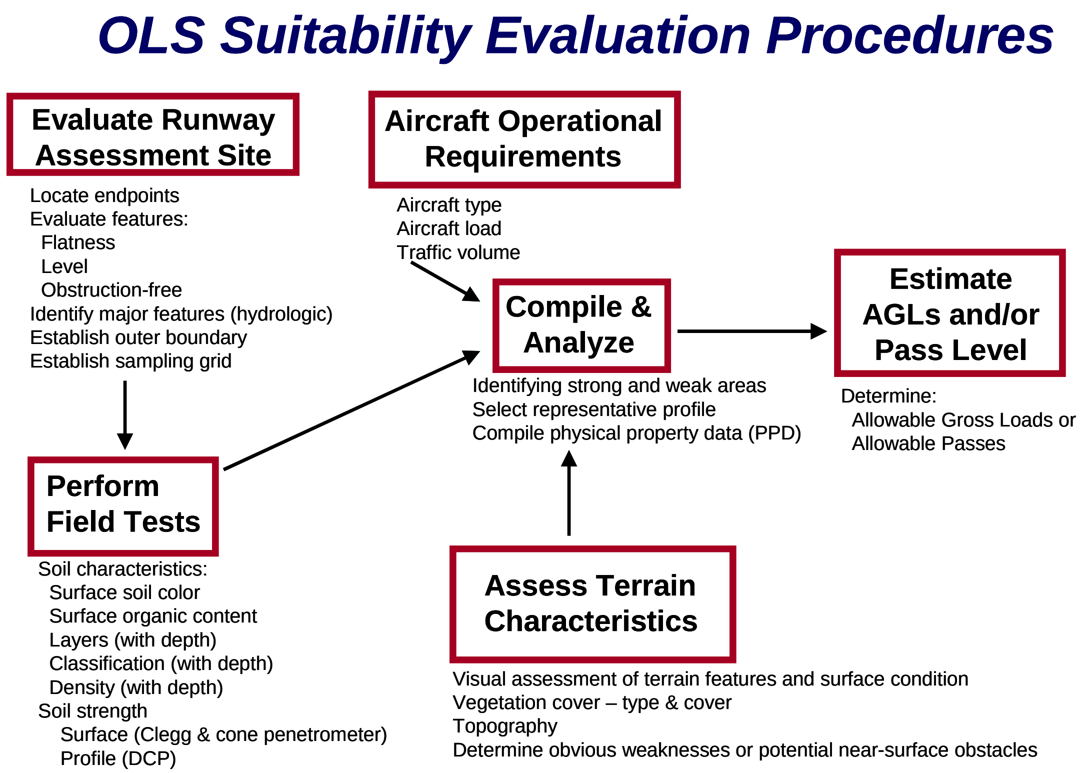


Figure 3-1. Procedures for evaluating the suitability of an OLS; adapted from ETL 2002-19 (Air Force 2002).

3.1 Evaluate RAS/SAS

Although the cursory evaluation conducted during the initial visit afforded a broad visual assessment of the candidate OLSs within a general interpretation of smooth, flat, and level, the measurements collected during the field program provided a way to quantify what was observed. The smoothness and flatness of the runway were noted and described in terms of undulation, inclination, or slope. Survey measurements were made during the field program to verify the length and width of the RAS, and determine the grade change in longitudinal and transverse directions. These measurements were compared to the guidelines specified in ETL 04-7 (Air Force 2004).

The length of each RAS was determined using the end points' output from the OLS-MS software. The end points generated from the software also established the RAS centerlines. A width of 20 m was used based on the requirements for an unpaved C-130 landing zone (Air Force 2004), and the outer boundaries of the RAS were established 10 m to either side of the centerline.

The term “level” refers to the change in the longitudinal gradient along the RAS centerline. For a C-130, the maximum allowable grade change is 1.5% per 61-m length and should be gradual (Air Force 2004). Changes in the transverse grade of the RAS described the flatness feature. The criteria in ETL 04-7 (Air Force 2004) states that the transverse grade should slope down away from the centerline at a minimum of 0.5%, not to exceed 3.0%.

Major obstructions were noted, if present, that were greater than 300 mm (12 in.) in height and that would significantly diminish the suitability of an RAS, such as power poles, drainage ditches, and dense vegetation. Hydrologic features, such as standing water, ditches, and streams were examined and measured to determine the length and width.

A sampling grid established the field measurement locations, spatially distributing the test points over the RAS. Similar sampling grids were used at both RAS locations and were used during all repeat seasonal visits. The sampling points were spread over each RAS, including measurements taken along both outer boundaries. The green dots in Figure 3-2 identify all of the sampling locations at the North Vernon Airport RAS where a minimum of one measurement was taken.

The figure also identifies the locations where soil pits were excavated (symbolized by the red diamond). The five soil pit locations were distributed along the length of the North Vernon Airport RAS at these survey points: 120 m, 2 m North; 180 m, 2 m South; 240 m, 2 m North; 300 m Centerline; and 480 m, 2 m South. The sampling station identifiers are in the following format: Station 120 m, 10 m West indicates the pit is 120 m from the RAS centerline start point and 10 m west of the RAS centerline. The soils pits, approximately 1.2 by 1.2 m (4 by 4 ft) were excavated to a depth of 0.6 m (2 ft). The intended excavation depth was 0.9 m, however, free water was encountered at depths of 0.6 m at the North Vernon Airport RAS (Fig. 3-3) and, therefore, excavation did not go beyond this depth.

In an effort to maximize the amount of information collected from the soil pits during the field visit, additional soil pits were excavated at sampling Stations 180 m, 2 m South and 240 m, 2 m North, down to a depth of 0.3 m. All of the soil pits were located either 2 m north or south of the centerline, with the exception of the soil pit at 300 m Centerline, corresponding to the location of a C-130 main-gear wheelpath. The soil pits at Stations

180 m, 2 m South and 480 m, 2 m South were located in touchdown areas of the RAS.

In addition to the North Vernon Airport RAS sampling stations, moisture, soil strength, and soil samples were collected near the subsurface instrumentation location (about 6 ft away from the automated weather observing system [AWOS] weather station). This was to confirm that the soil type and conditions near the instrumentation were similar to those on the RAS. These datum, however, were not included in calculating either the median or standard deviation due to the distance between this sampling point and the RAS.

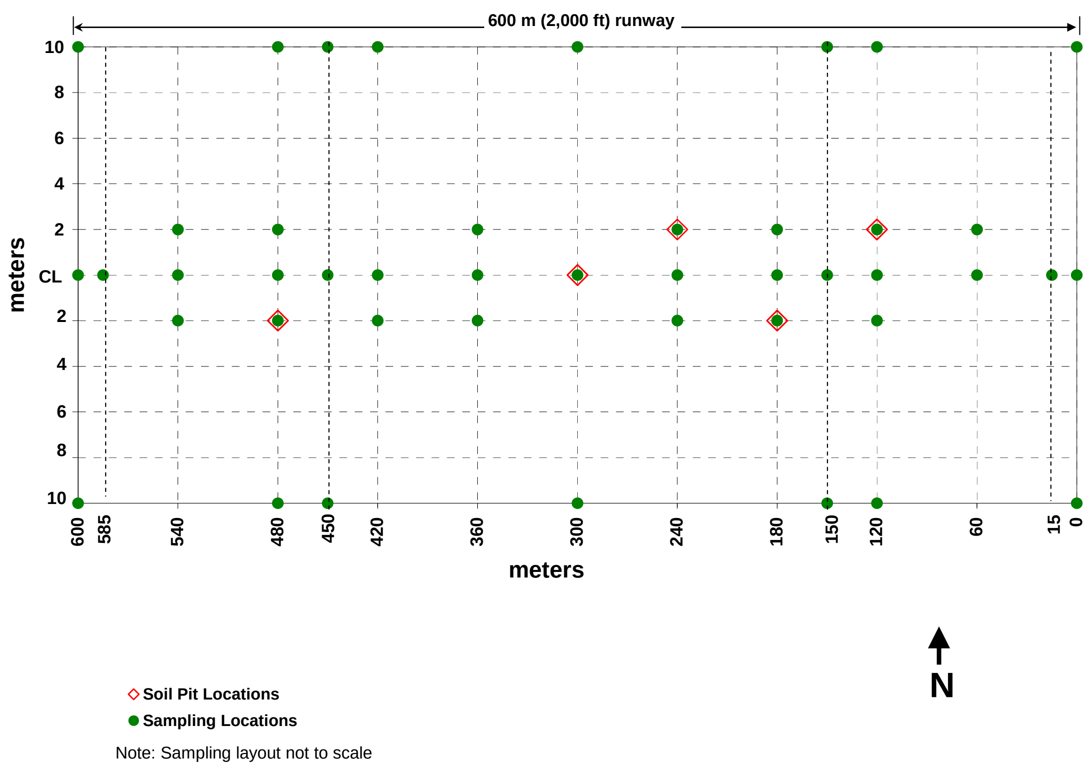


Figure 3-2. North Vernon Airport RAS sampling grid.

A similar sampling grid layout was used at the Ford Farm RAS (Fig. 3-4) where a total of six soil pits were excavated. Both 0.3- and 0.6-m (1- and 2-ft) soil pits were excavated for the same reasons as at the North Vernon Airport RAS. Three 0.6-m (2-ft) pits were excavated at sampling Stations 120 m, 2 m West, 300 m Centerline, and 480 m, 2 m East. Four0.3 m (1-ft) pits were excavated at sampling Stations 180 m, 2 m East, 420 m, 2 m

West, and on both the “dry” and “wet” (east and west sides, respectively) of the wet, rutted area at 84 m Centerline.

In contrast to the size of the RASs evaluated, each SAS location consisted of a large, flat, square area 60 x 60 m in size that was periodically tilled and kept free of vegetation throughout the entire testing period. A total of five sampling points were tested at each SAS (Fig. 3-5). One test point was located at the midpoint along each boundary edge of the test area, and one test point was located at the center of the square area. A soil pit was excavated, down to 0.6 m, at each of the center test point locations.

At both the RAS and SAS locations, boundary and interior sampling points were identified using a Trimble GPS Pathfinder. This system is designated as a “map grade” providing an accuracy of the positions to within 0.5 m when coupled with the continuously operated reference stations (CORS). The vertical datum was set using Delorme Topo USA digital map software (version 4.0) to determine the elevation of the sampling stations. A tripod-mounted automatic laser level was used with a telescoping rod equipped with a laser detector (Leica WILD LNA 20) to further refine the surface relief of the RASs only. The measurements were made at 5-m increments

Figure 3-3. Water moving up to the bottom of the soil pit. The imprint is from the base of the Troxler nuclear gauge where moisture-density readings were taken.

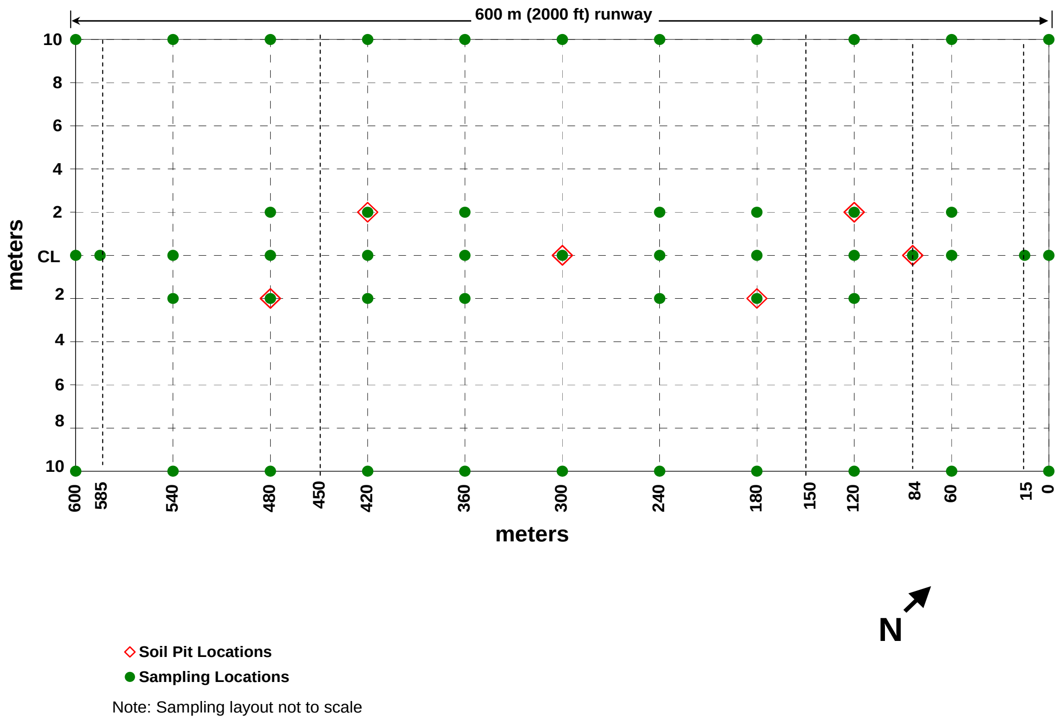


Figure 3-4. Ford Farm RAS sampling grid.

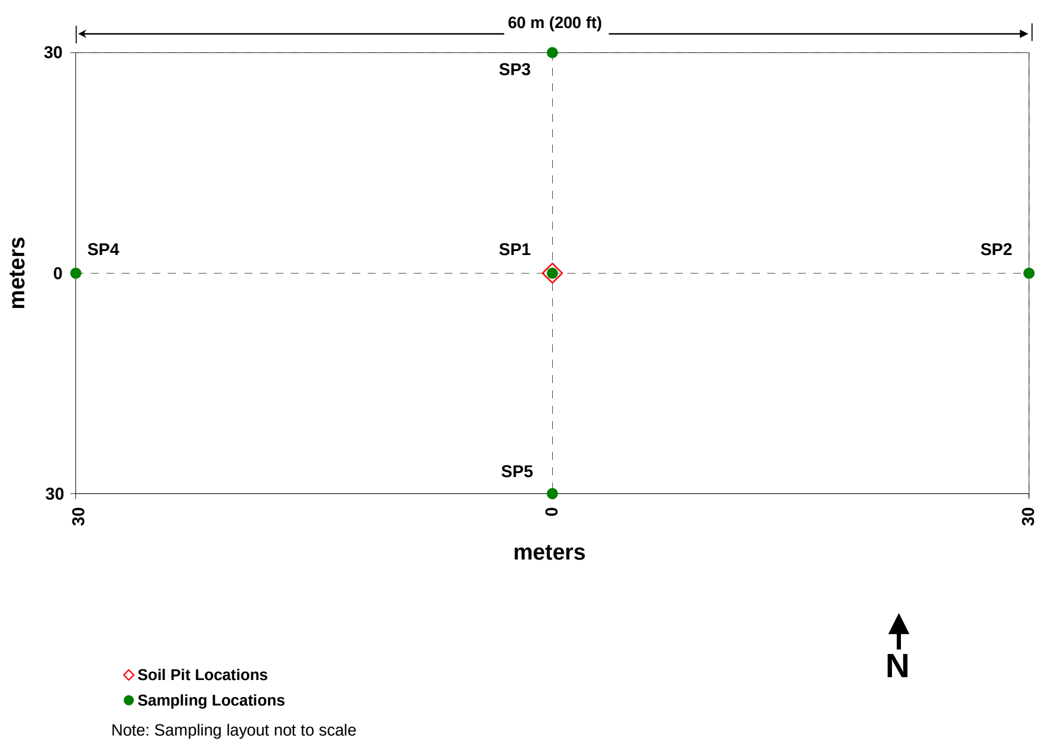


Figure 3-5. SAS sampling grids.

along the centerline of the RAS. A spacing of 1 m was used in areas of more subtle surface variation, such as the low-lying drainage ditches. The data from both the GPS and the laser level were compared.

3.2 Perform field tests

Once the RAS sampling grid was established, field tests were conducted to assess the soil properties and soil strength at the surface and at varying depths. Field measurements were divided into two categories: nonseasonal and seasonal for later evaluation of the software's capability of selecting OLSs seasonally. Soil field measurements collected at both the RAS and SAS locations that were anticipated to be unaffected by seasonal changes included: soil color identification, soil texture, and soil density. Soil samples collected from the soil pits at the surface and varying depths were used to determine the soil texture.

Soil moisture and soil strength were expected to be influenced by seasonal changes. For this reason, many of the field tests conducted each season focused on collecting as many of these measurements as possible. Soil organic content, also considered variable with seasonal change, was determined through laboratory testing using surface soil samples collected from the soil pit locations. Vegetative cover, type, and extent were also evaluated seasonally.

3.2.1 Nonseasonal conditions

Soil characteristics

Soil pits were excavated during IOP1 to determine the stratigraphy of the soil horizons, collect samples to determine the soil texture, and collect profile measurements of the soil density and moisture. At the soil pit locations, surface and subsurface soil information was gathered. The color of the surface soil only was identified using Munsell color chips (Rock-Color Chart 1991, Geological Society of America). This information was requested by The Boeing Company. The information was collected, but not further evaluated.

Soil samples collected from the soil pits at varying depths were used to determine the soil texture. Samples were collected on the surface before digging, and then at depths of 25–150, 300, and 600 mm (1–6, 12, and 24 in.) during excavation of the soil pits. The sample depths were based on the

location of distinct soil layers observed while excavating the initial pit and then used at the other pit locations.

As much vegetative debris as possible was removed by hand from the surface sample. Because the depth of disturbance from farm machinery may reach 200–300 mm, a representative soil sample was collected between 25 and 150 mm by scraping the pit sidewall using either a large spoon or flat scoop. Samples at depths of 300 and 600 mm were collected from the bottom of the soil pit. All samples were immediately placed in resealable bags and then double bagged to retain moisture (ASTM 1995). Double bagging also protects from any loss of material in case the bag breaks during shipment.

Soil samples were sent back and analyzed at the CRREL soils laboratory. The Unified Soil Classification System (USCS) soil type was determined in the laboratory using a mechanical sieve analysis and hydrometers following ASTM standards D 421 (ASTM 1985), D 422 (ASTM 1963), and D 2487 (ASTM 2006). Plasticity index values of the soil samples were determined following the ASTM D 4318 (ASTM 2005).

During IOP2, holes were augured using a portable gas-powered auger to take soil moisture readings below the surface. Soil samples were collected from the soil cuttings off of the auger bit at depths below 0.6 m to verify the soil type. During IOP3, soil pits were again excavated near the initial soil pit locations and down to the same 0.6-m depth, as during IOP1, to verify the soil density measurements using both the Troxler and drive cylinder methods.

Priority of the soil samples for laboratory analysis was given to those collected from the 0.6-m soil pits. In the event that significant inconsistencies were found from the lab analysis, then the samples from the 0.3-m pits (180 m, 2 m South and 240 m, 2 m North) would be analyzed to provide clarification.

Soil density

Density measurements are a routine quality control procedure to verify the density in mechanically compacted soils in construction projects, particularly in horizontal construction, such as roadways and airfields. The two methods used in the OLS project were the drive cylinder and nuclear method.

There are several reasons to measure soil density. First, soil density measurements of the natural soils at each RAS and the SAS are valuable in understanding density values in natural soils and, indirectly, their impact on the soil strength. These values will be used as input into computer models. Second, as-constructed density values are frequently reported for airfields. However, soil density values in natural soils are nearly nonexistent in the literature, particularly relating to austere airfields. The measurements taken during the OLS project will add to the body of knowledge currently available. Finally, the density measurements—specifically the dry soil density—are needed to convert the moisture content on a dry weight basis to a volumetric measurement to compare the instruments used to measure soil moisture content. Using measurements made in the field provides a higher confidence in the measurements as opposed to applying a value from the literature that may not fully represent the actual field conditions. From a practical standpoint, taking the measurements at the field site required equipment that is portable and easy to use.

At all of the field sites in Indiana, the density measurements were taken on soils used for agricultural purposes. The processed layer, typically 250–300 mm (10–12 in.) deep, experiences some partial compaction from heavy farm equipment during the times of the year when the fields are turned and planted, and possibly during the harvest several months later. Some variation would be expected in the processed layer, but at depths below any regular plowing activity, the soil density should remain reasonably constant.

The drive cylinder method consists of a cylinder, with both ends open, of a known volume (typically 0.01 ft^3); see ASTM D 2937 (ASTM 2004b). During the fall IOP3, drive cylinders were also collected to compare with the nuclear method. The cylinder is placed on the soil surface and driven into the soil with a drive hammer. The sample is retrieved and the soil is trimmed from the top and bottom of the cylinder using a metal flat edge. The sample is then sealed for shipment back to the laboratory. Errors range from –2.4% to –1.6% for wet density, and –4.6% to –2.2% for dry density (Rollings and Rollings 1996). Although the equipment for the drive cylinder method is portable, care must be used when trimming the sample. The samples also must be oven-dried, which typically means shipping them back to the laboratory for analysis unless an oven is available (either a portable field unit or access to a laboratory). The gravimetric moisture

content values were used with the wet density from the nuclear gauge to back-calculate the dry density values.

A Troxler nuclear density gauge (model 3440) was used during the spring and fall IOPs. The nuclear method was employed in the field and followed ASTM D 2922 (ASTM 2004a) and ASTM D 3017 (ASTM 2004c). The device is compact and fairly easy to transport; it is acceptable for both coarse and fine-grained soils (although not for gravelly material) as well as for both cohesive and noncohesive soils. Measurements may be made rapidly. One major disadvantage is that the device requires special training to transport and operate. Another is that the values determined by the gauge must be used with some degree of caution. Error ranges with the nuclear method for wet density are –5.1% to 4.2%, and –4.7% to +4.1% for dry density values (Rollings and Rollings 1996). The gauge reports the wet soil density and the weight of the mass of water in the soil volume. Using these two values, a calculated dry soil density and the water content on a percentage basis are determined. A comprehensive study by Coleman (1988) found that the wet density measurements at 6—12 in. tend to be fairly reliable values, but the moisture content tends not to be as accurate. However, using the wet density value from the gauge with an oven-dry moisture content from a sample collected at the same location where the density measurements were made, should provide a reliable dry density value.

The Troxler gauge was used in the direct transmission mode, according to the Troxler user's manual (Troxler 2003). In direct transmission, the source rod containing a small quantity of Cesium-137 is extended into the ground. Gamma radiation is emitted when the gauge is activated. Detectors in the base of the gauge measure the gamma photons coming from the tip of the source rod. The density measurement is an average over the distance between the base of the gauge and the depth of the extended source rod.

To measure moisture, the amount of hydrogen available is detected by the isotope of americium-241:beryllium. Before use at the start of each day, a standard count is taken to adjust for the rate of decay in the radioactive source between uses (Troxler 2003). To run a standard count, the gauge is set on the calibration block (Fig. 3-6a). The new standard count is compared to the average of the last four standard counts. The new standard count will pass if the density is within 1% of the average density, and the moisture content is within 2% (Troxler 2003).

To take a measurement, the surface of the soil is leveled using the scraper plate, then a hole hammered into the ground using the drill rod and a small sledge hammer. The gauge is then aligned with the hole, and the source rod is extended for direct transmission readings. Density readings were taken from the surface to 300 mm (12 in.) at increments of 50 mm (2 in.). For measurements below 300 mm (12 in.), the soil pit was excavated down to roughly 300 mm (12 in.), the bottom was leveled, and another set of density readings was taken. For the final set of measurements, the soil pit was excavated again to a depth of 600 mm (24 in.) and readings were taken to 900 mm (36 in.).

a.

b.

Figure 3-6. Troxler nuclear density gauge (a) taking a standard count before use and (b) taking density measurements in direct transmission mode with the source rod in the ground.

The Troxler gauge reports the wet density (expressed either as lbs/ft^3 or kg/m^3) and the weight of the water (M; expressed also as either lbs/ft^3 or kg/m^3) (Myers 2006). Also reported are the dry density (expressed either as lbs/ft^3 or kg/m^3) and the moisture content (expressed M% as a percentage based on mass). The dry density and moisture content are calculated by the gauge using the wet density and weight of the water. A reliable dry density value can be calculated by using the gravimetric moisture content of a soil sample collected in the vicinity of the density reading in conjunction with the wet density reading from the gauge (Rollings 2006). To accomplish this, use the following relationship.

$$Dry\_density = \frac{Wet\_density}{\left(1+\left(\frac{w}{100}\right)\right)}, \tag{3-1}$$

where:

$Dry\_density$ (lbs/ft³ or kg/m³)
$Wet\_density$ = reading from the Troxler gauge at 6 or 12 in. (lbs/ft³ or kg/m³)
w = gravimetric moisture content (%).

3.2.2 Seasonal conditions

Soil moisture

Soil moisture was measured during the field visits to assess seasonal changes to the moisture content of the soil. Changes to the soil moisture content will impact the bearing capacity of the soil, which will ultimately determine the number of aircraft passes that the soil can sustain. Soil moisture was measured two ways.

Volumetric moisture content readings were taken with depth using a Dynamax ThetaProbe ML2. Gravimetric soil moisture content measurements, expressed as a percentage of the dry weight of the soil, were obtained by oven drying soil samples, collected from the soil pits, in the laboratory. During IOPs when soil pits were not dug, a gas-powered auger was used to take moisture readings at depth (Fig. 3-7). This approach was not used more frequently because the soil cuttings came from a greater depth range (such as 305–610 mm [12–24 in.]).

3-7a. Station 60 m Centerline.

3-7b. Station 240 m Centerline.

Figure 3-7. Using auger to drill a hole to collect subsurface soil moisture readings.

Among the advantages to using the Dynamax ThetaProbe ML2 for volumetric moisture content readings are that the device is light and portable,

easy to use, less destructive (as compared to excavating a soil pit), and rapidly takes readings permitting many measurements to be taken on the RAS. The device operates by sensing changes to the apparent dielectric constant of the soil and reports the volumetric soil moisture content. The volumetric soil moisture content is the ratio of the volume of water in the soil mass to the total volume of the sample, expressed as a percent (% vol). The dielectric constant of water (~80) is much greater than either that of soil (~4–5) or air (1). Therefore, the dielectric constant of the water present in the soil matrix is considered the predominate component to measuring the soil moisture.

To obtain a volumetric soil moisture content from these measurements, the dielectric constant must be converted using a previously established relationship provided by the manufacturer. Previous work cited in the ThetaProbe Type ML2x soil moisture probe user manual (Delta-T Devices 1999), reports a near-linear correlation between the dielectric constant and the volumetric soil moisture content. At the bottom of the probe are four stainless steel rods, each 60-mm (2.25-in.) long, which are inserted into the soil. The rods transmit a 100-MHz electrical signal and from the reflected signal, measure the impedance. Factors that influence the measured volumetric soil moisture content include air pockets formed around the rods from inserting the probe, variation in soil density and composition, the presence of stones in close proximity to the rods, roots from vegetation, insect, and animal holes, and subsoil drainage (Delta-T Devices 1999). As stated in the user manual, the accuracy of the probe when applying the general calibration formula, including any associated measurement error, is ±6 $m^3 \cdot m^{-3}$ (Delta-T Devices 1999).

Gravimetric soil moisture values were determined from the soil samples collected for laboratory analysis following ASTM D 2216 (ASTM 1998). Soil sample collection is more labor and time intensive, requiring the excavation of soil pits to retrieve samples for analysis. For this reason, the number and locations of the soil pits were focused along the RAS centerline to provide the most relevant information. In geotechnical applications, soil moisture contents reported by dry soil weight are the accepted standard.

During the fall IOP3, the moisture measurements at the North Vernon Airport RAS were made using two different methods. The gravimetric moisture contents were determined from soil samples (drive cylinders)

collected in soil pits. The ML2 probe was used with the auger, as previously described. In addition, the sampling stations for the ML2 were located either on centerline or along the outside edge of the RAS. Therefore, the soil pits at sampling Stations 120 and 480 were excavated 2 m off of centerline, yet the ML2 readings were collected on centerline (120 Centerline and 480 Centerline), so there is a distance of 2 m between these sampling points.

Soil strength

The ability of a soil to resist shearing is of great importance, especially under dynamic loading conditions, such as aircraft operations. The California bearing ratio (CBR) value of a soil is an empirical method used to report the soil strength. It is reported as a percentage from 0 to 100, with 100 based on a high-quality, crushed, graded limestone material. Although there are several approved testing methods to obtain a CBR, the use of the dynamic cone penetrometer (DCP) is the accepted field testing instrument to determine the strength profile (Air Force 2002). One limitation to the DCP is that readings taken near the surface are less reliable, due to the lack of confinement of the soil at the surface (Air Force 2002). However, a depth of penetration of 3 in. for the DCP in fine-grained, plastic soils is considered an adequate depth for an accurate surface soil strength measurement (Air Force 2002).

Other common measuring tools used in the pavement engineering and vehicle mobility disciplines were used to measure the soil strength in the upper 75- to 150-mm (3- to 6-in.) layer including a Clegg impact hammer, an Army cone penetrometer, and a Dor-Cone. Because the Dor-Cone was only used during one IOP, there are insufficient data for comparison and it will not be further evaluated. Both the Clegg hammer and Army cone were used during multiple IOPs and the results from the data will be presented and discussed.

DCP

The DCP consists of a 16-mm (5/8-in.) stainless steel rod. At one end is a disposable cone tip that is driven into the ground using a sliding drop hammer. A complete description and the usage of the DCP is provided in ETL 02-19 (Air force 2002). The drop hammer consists of two weights. The heavier weight, 8-kg (17.6-lb) hammer, is used in coarse-grained materials and is dropped from a height of 575 mm (23 in.). A lighter, 4.6-kg

(10-lb) hammer, is used on fine-grained soils, such as those present at the Indiana sites. Recorded data include the accumulated penetration of the rod into the soil, which is read off of a measuring scale, and the number of hammer blows needed to reach that depth. Testing was done on the full length of the rod, or 900 mm (35 in.). It is recommended that there be a minimum rod penetration of 25.4 mm (1 in.) between readings.

A DCP index was calculated from the data using the number of blows and penetration with each blow set. Primarily, the soil CBR was estimated using the relationship for lean clay (CL) soils because this was the soil type present (Fig. 3-8; Air Force 2002). However, when the DCP value was outside the acceptable range to use the CL soil relationship, the DCP value was determined using the equation for "All Soils." The reason for using both relationships is that using the "All Soils" equation for all of the readings could overestimate the strength of the soil.

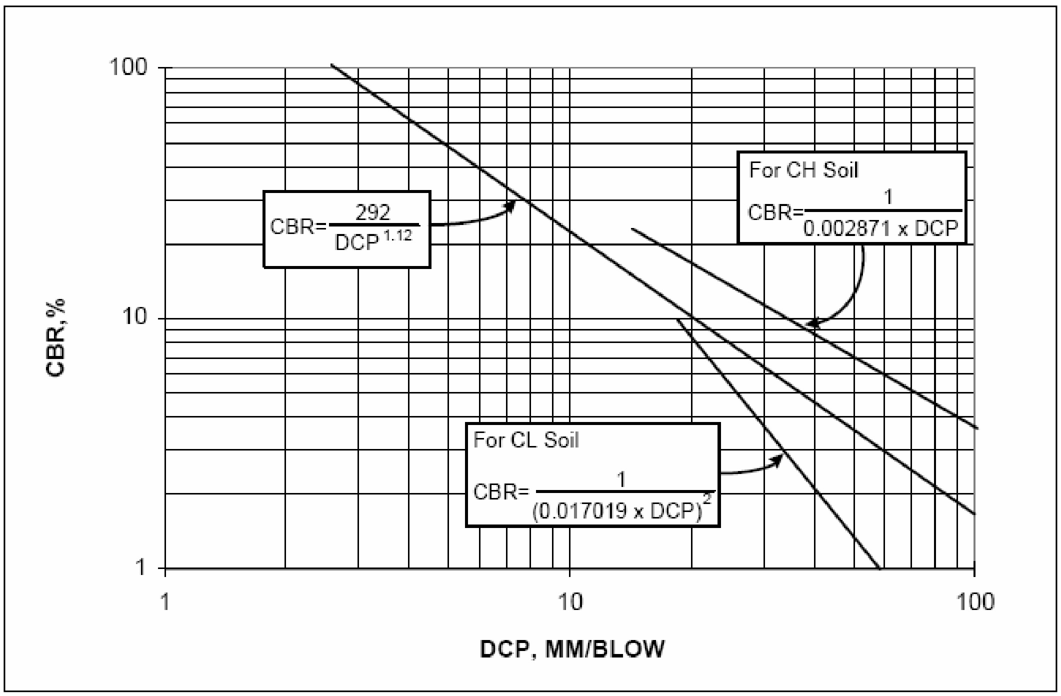


Figure 3-8. Relationships to estimate CBR for different soil types (Air Force 2002).

The data collected during each IOP were processed in a spreadsheet application using an automated program written by ERDC-CRREL to determine the CBR value at each sampling point. An average CBR value was calculated for every 150-mm (6-in.) and every 300-mm (12-in.) layer, described as 150-mm or 300-mm bins in the figures and tables presented

later. The average CBR value for the 300-mm layers divided the structure into three layers and was used to determine if the soil strength was adequate to support a minimum number of operations. For expedient airfields, using the C-130 as the design aircraft at a gross weight of 130 kips, a minimum CBR of 4.2 is required to support 10 traffic passes, as shown in Figure 3-10 (HQ Army and Air Force 1994; Air Force 2002). This value established the minimum CBR required for the surface layer.

Clegg impact hammer

The Clegg soil impact tester is commonly used for quality control to verify the materials compacted during highway and road construction. The test device is portable, easy-to-use, and nondestructive. It consists of a steel tube housing that encloses an impact hammer dropped from a specific height. There are several mass sizes available (0.5-, 2.25-, and 20-kg [1.1, 5, 44 lbs]) with the standard mass being 4.5-kg (10 lbs). The deceleration of the mass is determined by an accelerometer and reported as an impact value (IV). A relationship, based on testing results of a range of soil types, is used to estimate the soil CBR from the IV. The operating procedure is to set the device in a level location and hold it in place by standing on the flanges at the base of the tube. The hammer is lifted and dropped four times, with increasing readings after each drop. According to the user manual, any imperfections in the upper layer should be smoothed out with the first two drops, and readings should stabilize with the third and fourth readings (SDi 2000). The fourth IV reading is used to estimate the soil CBR. During the spring IOP, numerous attempts were made at all of the test sites to use the standard Clegg hammer for strength measurements in the upper soil layer. These attempts failed as the soil was not strong enough to withstand the impact from the mass, leaving an indentation more than 25 mm (1 in.) deeper than the permitted 20 mm (0.78 in.) for a successful test as shown in Figure 3-9 (SDi 2000), and a value of zero on the readout device. In addition, the test is not valid if the hammer drop height is decreased.

Beginning with the summer IOP, a lightweight, 0.5-kg (1.1 lbs), Clegg hammer was evaluated for this purpose. While it is lightweight, compact, and easy to use, one limitation was the number of test points that must be repeated when the soil surface contains numerous discontinuities (dried out and cracked). The relationship used to estimate the CBR value is:

$$CBR = \left(0.014 \times \left(4^{\text{th}}\, Drop^{2}\right)\right) + \left(0.0199 \times 4^{\text{th}}\, Drop\right). \tag{3-2}$$

Cone penetrometer

When it first became apparent that the standard Clegg hammer was unsuitable for taking soil strength measurements during the spring IOP1, a vehicle cone penetrometer served as an alternative tool. The cone penetrometer is a testing device used to expediently determine the trafficability of soils (HQ Army and Air Force, 1994). It consists of a steel rod 16 mm (5/8 in.) in diameter and 483mm (19 in.) long, tipped with a 30° cone having a 322-mm^2 (0.5 in^2) base. This tip size is suitable for fine-grained soils. On the top of the rod is a proving ring with a micrometer dial ranging from 0 to 68 kg (0–150 lbs), although some dials range up to 137 kg (300 lbs). The dial reading is a cone index value indicating the soil's shear resistance. To operate the instrument, the rod is set vertically on the surface of the soil and with a steady downward force, the tip is pushed into the soil. Dial readings are recorded at designated intervals. The data are processed by calculating an average of the dial readings in 152-mm (6-in.) increments (from the top of the cone to 150 mm [6 in.], and then 150–300 mm [6-12 in.]). The CBR was estimated using the following exponential relationship based on data collected using a small-aperture CBR test and laboratory data collected at ERDC-CRREL (Shoop et al. 2008):

$$CBR = 0.1266\left(CI^{0.6986}\right). \tag{3-3}$$

Figure 3-9. Typical indentation when attempting to use the standard (4.5-kg) Clegg hammer for upper soil strength measurements.

Soil organic content

A portion of the surface soil samples collected to determine soil texture were also used to test for organic content in accordance with ASTM D 2974 (ASTM 1971). Test Method A was used to determine the moisture content; Method C, an accepted method used for geotechnical applications, used a muffle furnace to determine the ash content. The surface soil samples collected at the same locations as the soil pits were split using a portion for the texture analysis, hydrometers, and organic content testing.

3.3 Assess terrain characteristics

Assessment of terrain characteristics involved a visual surface condition inspection of the RAS to record the near-surface terrain conditions in greater detail to identify hazard areas to aircraft operations. The near-surface is considered to be within approximately 300 mm above or below (such as in the case of a drainage ditch) the horizontal plane of the natural terrain. This step identified inconsistencies along the length of OLS where the soil structure is potentially too weak (such as areas of ponding surface water) to support aircraft operations without resulting in excessive damage to the surface of the landing zone, or areas where OLS surface deficiencies may cause damage to the aircraft (an example is small, loose surface material being ingested into aircraft engines). Potentially weak areas will impact either the number of landing and takeoff operations, or the allowable gross weight of the aircraft that the OLS will support.

3.3.1 Terrain features and surface condition assessment

Procedures for evaluating and rating either semi-prepared or unsurfaced pavements are described in ETL 2002-19 (Air Force 2002) and provide the basis for OLS terrain characterization. This criteria has been established for C-17 aircraft operations. Roughness requirements for unsurfaced expedient airfields for both the C-17 and C-130 are described in Field Manual, Planning and Design of Roads, Airfields, and Heliports in the Theater of Operations – Airfield and Heliport Design (HQ Army and Air Force 1994). The features of the OLS were documented during a ‘walk-through’ conducted seasonally during each IOP at each RAS. A ‘walk-through’ entails examining the entire area of the RAS and documenting the physical characteristics. The severity of the features were rated to determine the extent and severity of any hazards on the RAS. The types of OLS features documented and evaluated included, but were not limited to:

- Potholes or depressions – typically well defined bowl-shaped cuts in the ground surface. This also includes any animal burrows and surface scouring caused by wildlife or farm animals that would weaken the support of the OLS for aircraft operations.
- Ruts – surface depressions of 300 mm (12 in.) or less made from mechanical equipment, such as farm equipment or motorized vehicles, particularly within the wheel path.
- Rolling resistance material – loose surface material, such as from tilling, that increases friction upon takeoff requiring a longer takeoff distance for the aircraft.
- Dust – loose material that is scattered into the air when disturbed.
- Vegetation – the type and area of coverage of plant material found on the RAS. Vegetation of certain types, such as bushes or a field of corn, may impede aircraft operations.
- Standing water / wet areas – ponded surface water indicates poorly draining soils resulting in weak areas.
- Surface drainage paths - patterns of flow when runoff occurs that cause surface roughness.
- Rock outcropping – rock at the OLS surface that, if unavoidable, would be an obstruction prohibiting aircraft operations.
- Snow classification – in areas of seasonal change the presence of a snow layer would be noted.

In the process of determining the surface condition of an RAS, it became clear that not all of the features listed would be applicable and some modification may be required. During the initial site visit, the condition of the RAS surface was noted along with permanent features, such as the location of major drainage ditches at North Vernon Airport RAS. The extent of the vegetation coverage during the summer IOP2 is unmistakable due to the presence of crops; therefore, the description for both the fall and winter IOPs is more extensive. The OLS Data Archive (Scott et al. in press) contains a feature file for each Indiana RAS (Surface Feature File, or SFF) and a collection of photographs taken during each IOP showing the surface condition at specific stations along the RAS centerline (where applicable, these are included in the soil field measurement files).

The criteria in Table 3-2, as related to C-130 aircraft, describes the types of obstacles that may be encountered, the limits to which the obstacle may impede operations, and the necessary action for mitigation (HQ Army and Air Force 1994).

3.3.2 Vegetation

Samples of the vegetation growing on the OLS were collected to identify the species and/or vegetation name. Photos were taken along the runway to estimate the vegetation cover.

3.3.3 Topography

The topography of the runway was determined from survey elevation at each sample location on the sampling map, as described earlier in this section. Lateral and longitudinal profiles of the runaway were derived to examine whether runway flatness is acceptable. A more detailed profile of the runway centerline was also measured, this information may also be used to determine surface roughness or undulation.

Table 3-2. Expedient airfield smoothness requirements (HQ Army and Air Force 1994).

	Obstacle Types	Limit Threshold	Action
1.	Rocks and tree stumps		Rocks, remove or push in Tree stumps, cut back to 2 in. above ground
2.	Dirt clods and hardened balls of soil	6-in. diameter	Remove or crush
3.	Dirt patterns	Allowable if formed from drainage or plowing	Removal not required due to soft interior core
4.	Rutting	Maximum rut depth is 3 in. for any orientation angle from centerline	
5.	Potholes	>15-in. diameter at widest point and 6-in. depth with angular edges	Fill in
6.	Ditches	>6-in. deep	Fill in and compact to similar soil strength of surrounding soil

3.4 Aircraft operational requirements

Knowledge of the aircraft type, gross loads, and traffic volume is necessary when evaluating an OLS and its potential capacity, since the bearing capability of the airfield will dictate the allowable gross weight of the aircraft and the overall number of operations that may be conducted. In this investigation, while no specific aircraft mission was defined, the OLSs were evaluated for their suitability to support a minimum number of C-130 operations at a gross aircraft weight of 130 kips.

3.5 Compile data

All of the data collected to characterize an OLS are compiled to assist in identifying stronger or weaker areas and any other limitations of the OLS. The OLS may then be separated into representative areas based on the thickness and types of the soil layers, the soil strength, etc. This information can be used to estimate the aircraft allowable gross load and/or the number of aircraft passes.

3.6 Estimate allowable gross loads or pass level

All of the information obtained to characterize an OLS are used in conjunction with the evaluation curves, Figure 3-10, established in ETL 2002-19 (Air Force 2002) to determine the allowable gross load (AGL) and allowable number of passes for the design aircraft. Typically, information pertaining to a specific mission is used to determine the AGL and number of passes. However, knowing the structural capacity of the OLS, the maximum number of passes, and the types of aircraft that may operate on the OLS may be estimated.

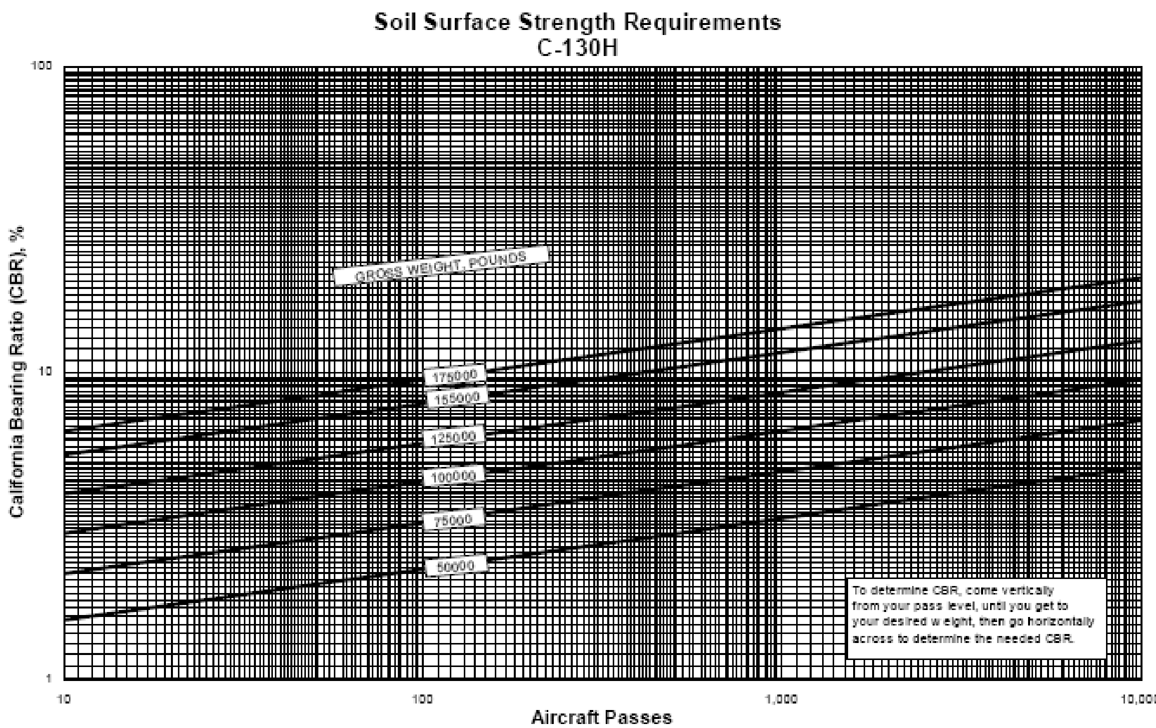


Figure 3-10. Chart to determine either allowable aircraft gross weight or allowable pass level for C-130 aircraft (from Air Force 2002).

4 North Vernon Airport RAS

4.1 Site description

North Vernon Municipal Airport is located approximately 6.4 km north of the city of North Vernon in Jennings County, in the southeastern portion of Indiana. The North Vernon Airport RAS is oriented in an east-west direction and located in an actively farmed field owned by the municipal airport. Permission from the landowner(s) was obtained before the start of field testing. Figure 4-1, taken during the summer 2005 field visit, shows an aerial view looking eastward of the field where the RAS was located and the surrounding area. The RAS is 600-m long and 20-m wide. Corn was planted during the spring of 2005. At the time the photograph was taken, the height of the corn was roughly 2.5 m. The RAS is bounded by N Base Road to the east and an elevated railroad grade, obscured by deciduous trees, to the west. There is a distance of approximately 30 m between the west end of the RAS and the tree line. Left of center in the photograph is a drainage ditch, located to the north of the RAS. The diagonal lines in the photograph indicate the location of large, subsurface drainage tiles, installed 1.8–2.5 m below the soil surface to aid in draining the soil due to the presence of a shallow water table.

4.2 Evaluate RAS

Field activities during IOP1 included surveying the site to lay out the RAS sampling grid (Fig. 3-2). The sampling stations were distributed along the RAS between the centerline start and end points. This corresponds to northing 4322430 m, easting 620010 m for the RAS start point at the eastern end, and northing 4322429.99 m, easting 619410.22 m for the RAS end point at the western end, based on WGS84 UTM Zone S16. A complete summary of all measurements recorded during each IOP and at each sampling station is given in Table B-1, Appendix B.

The GPS survey data were collected during IOP1 and shows a decrease in the longitudinal grade of 3.5 m (0.6%) over the length of the RAS from east to west, as illustrated in the contour map (Fig. 4-2). The laser level data, collected during IOP4, were compared with the GPS survey data (Fig. 4-3). Both sets of data show the decrease in elevation along the centerline

Figure 4-1. An aerial view of the North Vernon Airport RAS location taken during the summer 2005 field visit. The location of North Vernon Municipal Airport runway is indicated at the top of the photograph.

of the RAS. The detail in the laser level data clearly shows the locations and depths of the drainage ditches and other surface imperfections that the total station data do not show at this resolution. Notice there is a difference of as much as 200 mm between the two sets of data. This difference may be attributed to a change in the surface when the field had been harvested in the fall. A surface rut, approximately 80-mm deep, located at the RAS start point is likely to have contributed to the discrepancy in the readings because this established the initial datum.

Both the length and location of the North Vernon Airport RAS do not strictly meet the required geometry for either the C-130 or C-17 aircraft (Air Force 2004) because the RAS does not include the needed length for overruns, runway end, clear or accident potential zones, or exclusion areas. This is acceptable because this technology is still in the research phase and these concerns could be incorporated in the

future. The intention of this study is only to demonstrate the feasibility of the technology.

As shown in Figure 4-3, the total change in the longitudinal runway grade is 0.6%, with less than a 0.1% change every 60 m (200 ft). As specified in the criteria (Air Force 2004), the maximum longitudinal runway grade is 3%, with a maximum grade change of 1.5% per 60 m (200 ft). The North Vernon Airport RAS is within this limit.

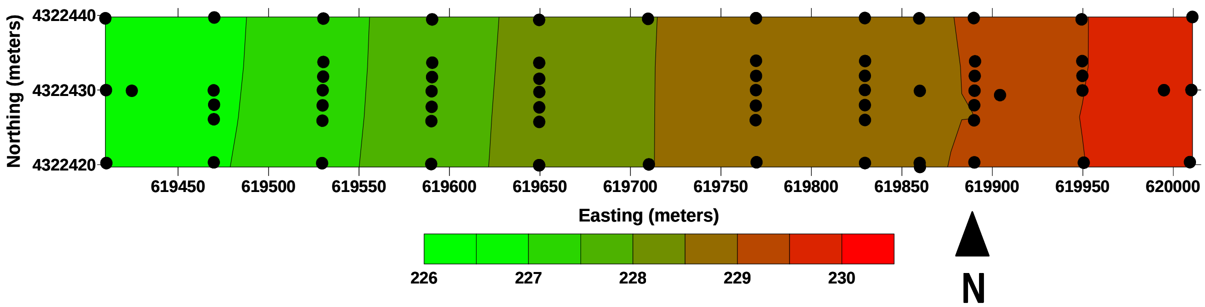


Figure 4-2. Contour map of North Vernon Airport RAS showing elevation based on survey points (indicated by solid circle symbol).

4.3 Field testing

4.3.1 Nonseasonal conditions

This section describes the soil field measurements collected at the North Vernon Airport RAS site unlikely to be affected by seasonal change: soil texture, soil color identification, and within limits, soil density. Taken during IOP1, the photographs in Figure 4-4 show the in situ surface condition at each soil pit excavated at the North Vernon Airport RAS (locations shown in Fig. 3.2).

Soil characteristics

In general, the soil in the upper 300 mm consists of a silty clay with sand (CL-ML) overlying a lean clay (CL) below 300 mm. The range of values for the plasticity index in the upper 300 mm is from 4 to 17, and there is a high percentage—greater than 70%—of material finer than 0.074 mm (#200 sieve). Beneath 300 mm the plasticity index ranges from 7 to 19.

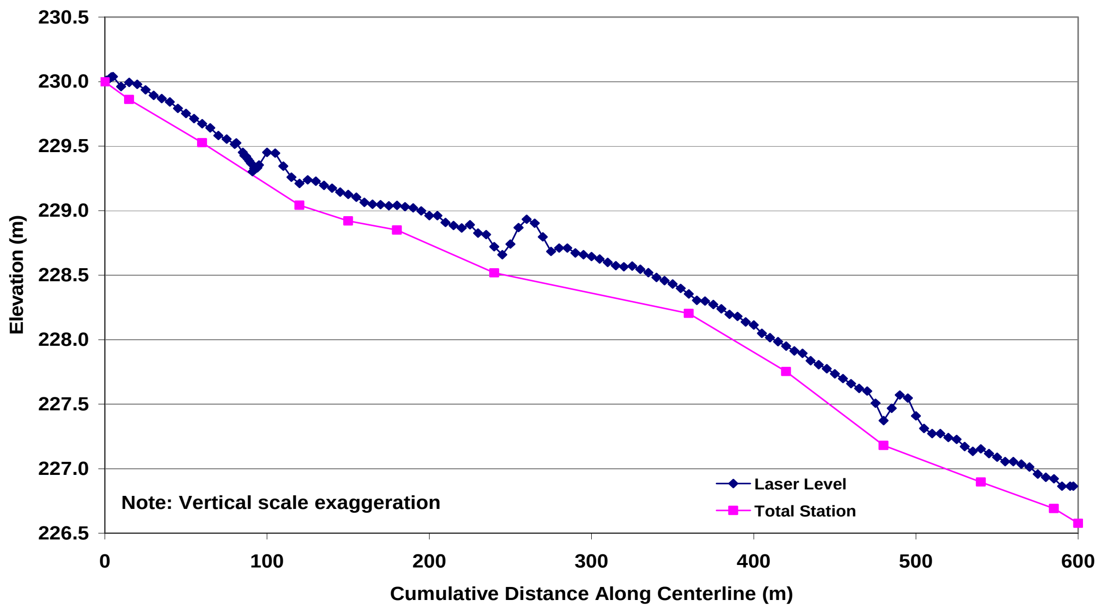


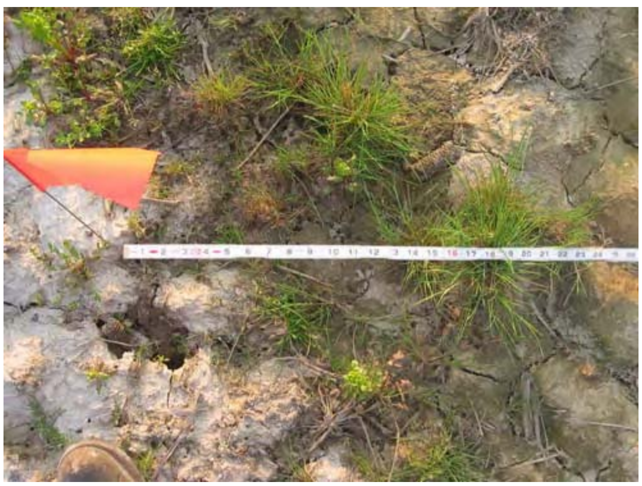
Figure 4-3. Elevation change over length of North Vernon Airport RAS.

Table 4-1 summarizes the physical properties of the soil samples analyzed from the North Vernon Airport RAS, and the grain size distributions of the surface soil samples are given in Figure 4-5. Grain size distributions for the other soils sampled at the North Vernon Airport RAS are given in Figures B-1 to B-5, in Appendix B.

The grain size analysis also reveals a high percentage of fine material (75% and above) passing the #200 sieve. This indicates how well water drains from the soils. In a soil survey conducted by the U.S. Department of Agriculture (Nickell 1976), these soils are described as poorly draining. The RAS is located in a geographic location that experiences seasonal changes. Based on the percentage of material finer than the #200 sieve, the U.S. Army Corps of Engineers frost susceptibility criteria as presented in Table 4-2 (Department of the Army 1985) classifies these soils as either F3 or F4, depending on the plasticity index. F4 soils have a frost susceptibility range of medium to high. During freezing periods, this soil type has the potential to heave and significantly lose bearing strength during periods of thaw.

4-4a. 120 m 2 m North

4-4b. 180 m 2 m South



4-4c. 240 m 2m North

4-4d. 300 m Centerline

4-4e. 480 m 2 m South

Figure 4-4. In situ surface condition at North Vernon Airport RAS soil pit locations.

Table 4-1. Summary of physical soil properties at the North Vernon Airport RAS.

	Sampling Station																	
Soil Properties	240 m 2 m North	240 m Centerline	480 m 2 m South	120 m 2 m North	300 m Centerline	480 m 2 m South	120 m 2 m North	300 m Centerline	480 m 2 m South	120 m 2 m North	300 m Centerline	480 m 2 m South	480 m Centerline[a]	540 m Centerline[b]	120 m 2m North	480 m Centerline[c]	540 m Centerline[d]	Weather Station[e]
Depth below surface	Surface			25–152 mm (1–6 in.)			305 mm (12 in.)			610 mm (24 in.)			305–660 mm (12–26 in.)		610–890 mm (24–35 in.)			
Season sample collected	Spring			Spring			Spring			Spring			Summer		Fall	Summer	Summer	Fall
USCS soil description	CL Lean clay w/ sand	CL Lean clay	ML/CL-ML Silt w/ sand	CL-ML Silty clay w/sand			CL-ML Silty clay	CL-ML Silty clay w/sand		CL Lean clay	CL Lean clay w/sand		CL Lean clay	CL-ML Silty clay	CL Lean clay			
Liquid limit	32	39	33.7	26	24	25	25	24	23	26	28	26	29	25	26.3[f]	27	28	33
Plasticity index	12.1	16.9	9.7	5	6	5	6	5	4	19	10	8	9	7	—	9	10	15
% Fines	81.3	86.2	82.2	79.6	73.6	82.3	85.3	75.0	81.6	87.7	78.3	81.6	86.4	85.9	87.8[f]	87.6	87.1	88.4
Specific gravity	No data	No data	No data	2.61	2.64	2.60	2.61	2.62	2.62	2.57	2.57	2.62	2.66	2.64	2.60[f]	2.62	2.64	2.62

Notes:

[a]Sample depth was 12–24 in. below the surface.

[b]Sample depth was 12–26 in. below the surface.

[c]Sample depth was 24–31 in. below the surface.

[d]Sample depth was 26–31 in. below the surface.

[e]Sample depth was 23–30 in. below the surface.

[f]Average values from three sample depths (24–27.5, 28–31, and 32–35 in.).

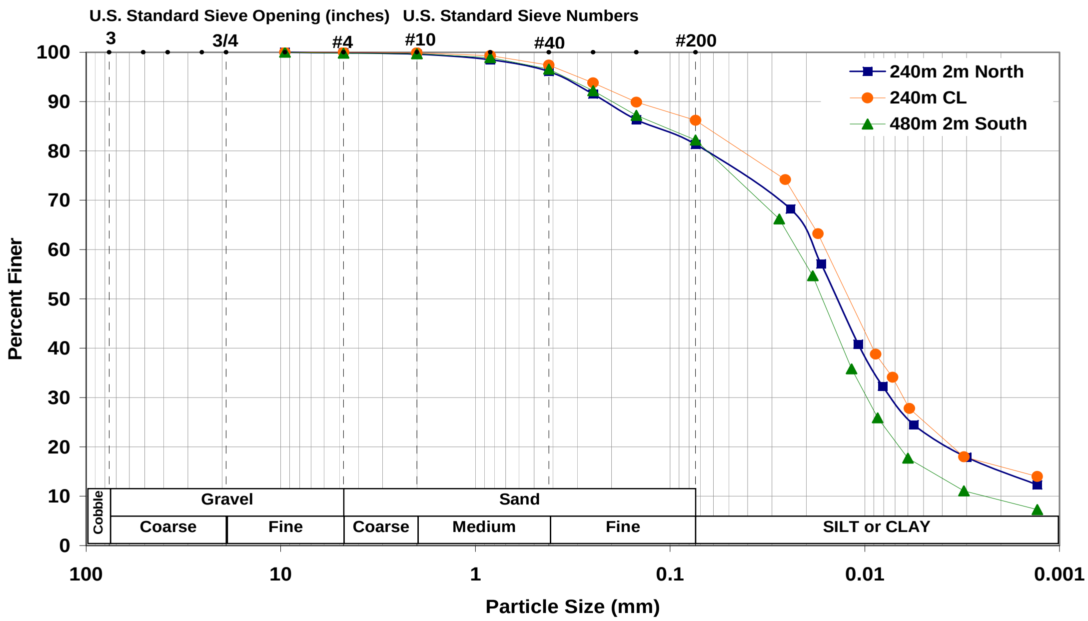


Figure 4-5. Gradation analysis for North Vernon Airport RAS surface soil samples.

The North Vernon Airport RAS soil profile analyzed is 305 mm (12 in.) of silty clay with sand (CL-ML) overlaying full-depth lean clay (CL). The CL-ML layer is likely not always consistently 305-mm thick, and may vary in thickness by 50 mm or so, but the simplified structure should adequately capture the soil layers present at the OLS.

Plotting the Atterburg limits (liquid limit and plasticity index) on a plasticity chart (Fig. 4-6) shows the classification of these samples. The material from sampling Station 480 m 2 m South classifies as a silt with sand (ML/CL-ML), falling on the “A” line between a silt (ML) and clay (CL) material. Soil samples from sampling Stations 480 m and 540 m Centerline were collected from the auger cuttings during IOP2, and show that the soil type remained consistent.

The photographs in Figures 4-7 and 4-8 show examples of the material in the upper and lower layers of the soil pits. Figure 4-7 is from the upper 300 mm at the soil pit located at 480 m 2 m South and is representative of the upper layer along the RAS. There is a distinct change in the soil color,

Table 4-2. Soil frost susceptibility classification (Department of the Army 1985).

Frost Group	Soil Type	% Finer than 0.02 mm by Weight	USCS Typical Soil Types
NFS[a]	a. Gravels	0–1.5	GW, GP
	Crushed stone	—	—
	Crushed rock	—	—
	b. Sands	0–3	SW, SP
PFS[b]	a. Gravels	1.5–3	GW, GP
	Crushed stone	—	—
	Crushed rock	—	—
	b. Sands	3–10	SW, SP
S1	Gravelly soils	3–6	GW, GP, GW-GM, GP-GM
S2	Sandy soils	3–6	SW, SP, SW-SM, SP-SM
F1	Gravelly soils	6–10	GM, GW-GM, GP-GM
F2	a. Gravelly soils	10–20	GM, GW-GM, GP-GM
	b. Sands	6–15	SM, SW-SM, SP-SM
F3	a. Gravelly soils	>20	GM, GC
	b. Sands, except very fine silty sands	>15	SM, SC
	c. Clays, PI > 12	—	CL, CH
F4	a. All silts	—	ML, MH
	b. Very fine silty sands	>15	SM
	c. Clays, PI < 12	—	CL, CL-ML
	d. Varved clays and other fine-grained, banded sediments	—	CL, CL-ML,CL and ML; CL, ML, and SM; CL, CH, and ML; CL, CH, ML, and SM

[a]Non-frost-susceptible.
[b]Possibly frost-susceptible, but requires laboratory test to determine frost design soils classification.
PI, plasticity index.

most likely from farming. Figure 4-8 shows a close-up of the soil pit at Station 300 m Centerline. The soil pictured in Figure 4-8 is representative of the bottom soil layer found at the soil pit locations in the RAS. As the soil pits were excavated, there were many large pore spaces encountered from worms, snakes, and crayfish, whose mounds (Fig. 4-9) were scattered over the surface of the North Vernon Airport RAS.

Soil color

Table 4-3 summarizes the surface soil color at the specified sampling stations.

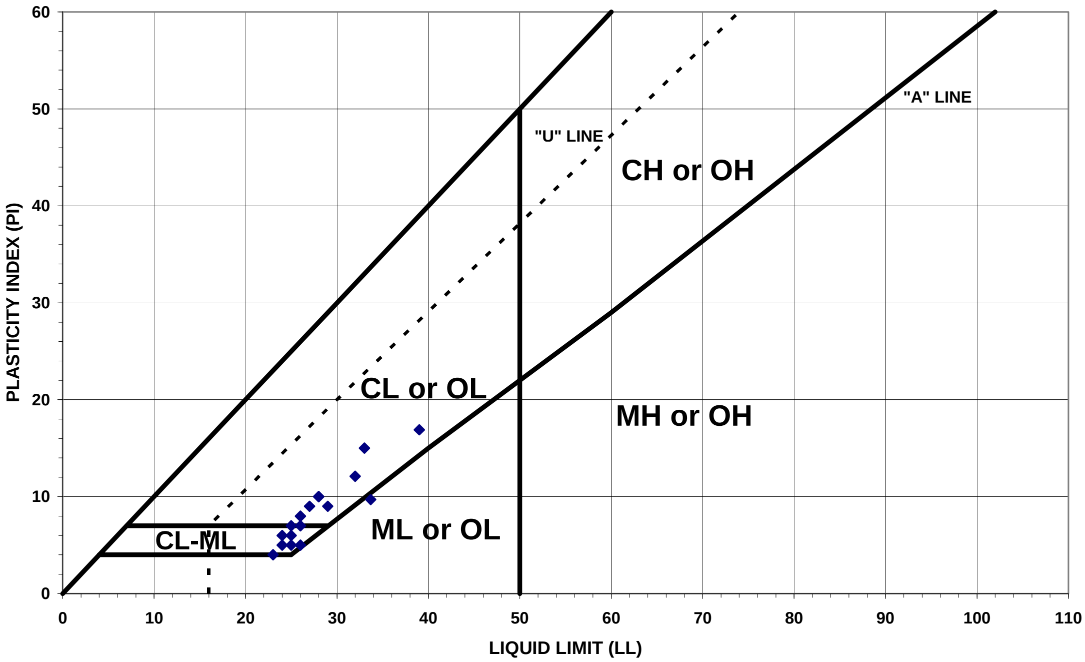


Figure 4-6. Plasticity chart for soil samples from North Vernon Airport RAS.

Figure 4-7. Station 480 m 2 m South, upper 300 mm of soil pit. Note the color change in the soil at the bottom of the pit.

Figure 4-8. Close-up of mottled soil at bottom of pit, Station 300 m Centerline.

Figure 4-9. Crayfish mound on North Vernon Airport RAS.

Table 4-3. Summary of Munsell soil color identification at the North Vernon Airport RAS.

	Sampling Station												
	240 m 2 m North	300 m Centerline	480 m 2 m South	0 m Centerline	15 m Cen-terline	60 m Centerline	120 m Centerline	180 m Centerline	240 m Cen-terline	300 m Centerline	360 m Centerline	420 m Centerline	540 m Cen-terline
Season sample collected	Spring			Winter									
Munsell color identification	10 yr 6/2 Pale yellow-ish brown	10 yr 6/2 Pale yellow-ish brown	10 yr 6/2 Pale yellow-ish brown	10 yr 4/2 Dark grayish brown	10 yr 4/2 Dark grayish brown	10 yr 4/2 Dark grayish brown	10 yr 4/2 Dark grayish brown	10 yr 4/2 Dark grayish brown	10 yr 6/2 Light brownis h gray	10 yr 4/2 Dark grayish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 4/2 Dark grayish brown

Soil density

As shown in Figure 4-10, the soil dry density values are reasonably consistent along the length of the RAS. The average dry density in the upper 305-mm CL-ML layer is 1,473 kg/m^3 (92 lbs/ft^3). At depths between 305 and 610 mm, the dry density is the same at 1,537 kg/m^3 (96 lbs/ft^3). In the lower layer, the average dry density slightly decreases to 1,457 kg/m^3 (91 lbs/ft^3).

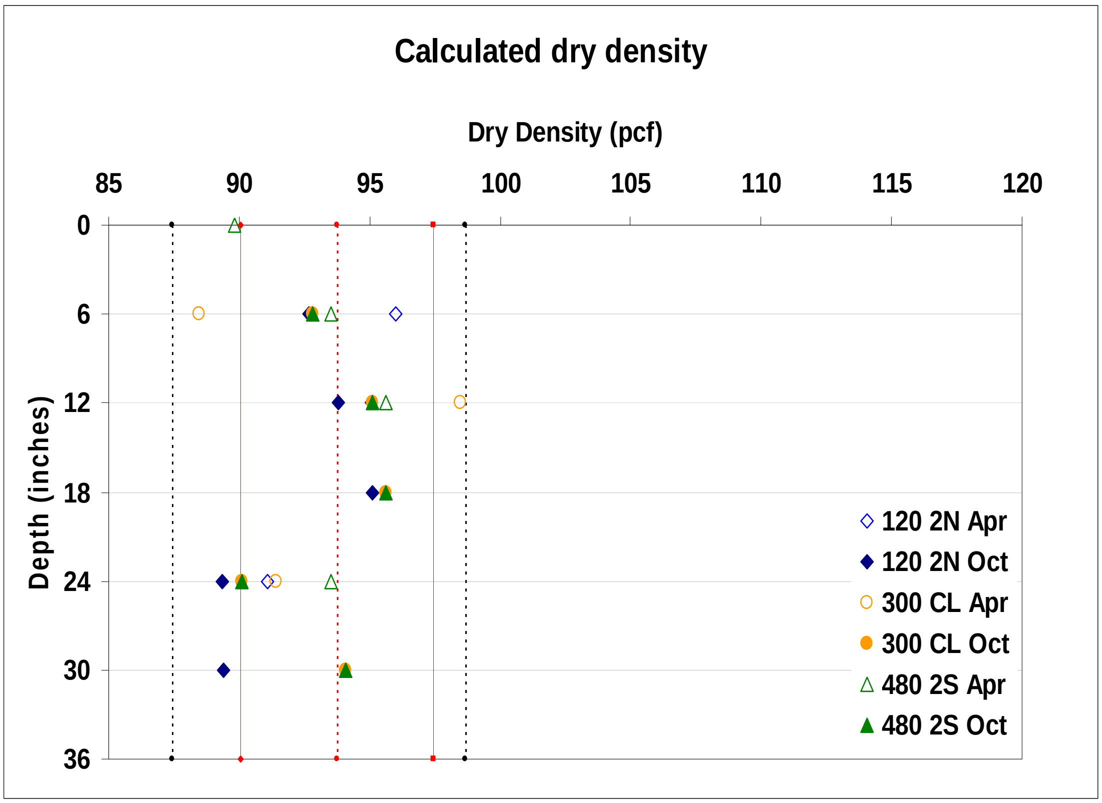


Figure 4-10. Calculated soil dry density for North Vernon Airport RAS.

4.3.2 Seasonal conditions

This section discusses the North Vernon Airport RAS characteristics influenced by seasonal changes including: surface condition, soil moisture, soil strength, and surface soil organic content. Because this locale is actively farmed, the changes to the surface condition during each season are dramatic. Changes to the surface condition may impact potential landing sites identified by the OLS-MS software. During each IOP, only a small portion of bare soil was exposed on the RAS due to the extent of coverage from vegetation. In general, the surface condition during both the spring and winter IOPs consisted of low-growth vegetation and dead plant debris scattered over the surface. The summer saw a crop of tall, densely planted corn that dried on the stalk and was harvested at the very end of the fall IOP3, the cut stalks leaving rows of 'stubble' and dried vegetation residue over the soil surface.

The seasonal change also impacts both the soil moisture and soil strength. This region may receive nearly 1.1 m (44 in.) of precipitation in a year either as rain or snowfall (Nickell 1976). This moisture combined with the presence of poorly draining soils and a shallow water table will impact the bearing capacity of the RAS. It is assumed that the organic content may change seasonally due to the farming activities.

The southeastern region of Indiana has four distinct seasons. The local weather is influenced by the movement of polar and tropical air masses, which also bring ample precipitation throughout the year (Nickell 1976). Both the maximum and minimum average daily temperatures and the average monthly precipitation total are shown in Figure 4-11 (after Nickell 1976). During the winter months, air temperatures fall to freezing or below and some snowfall may occur.

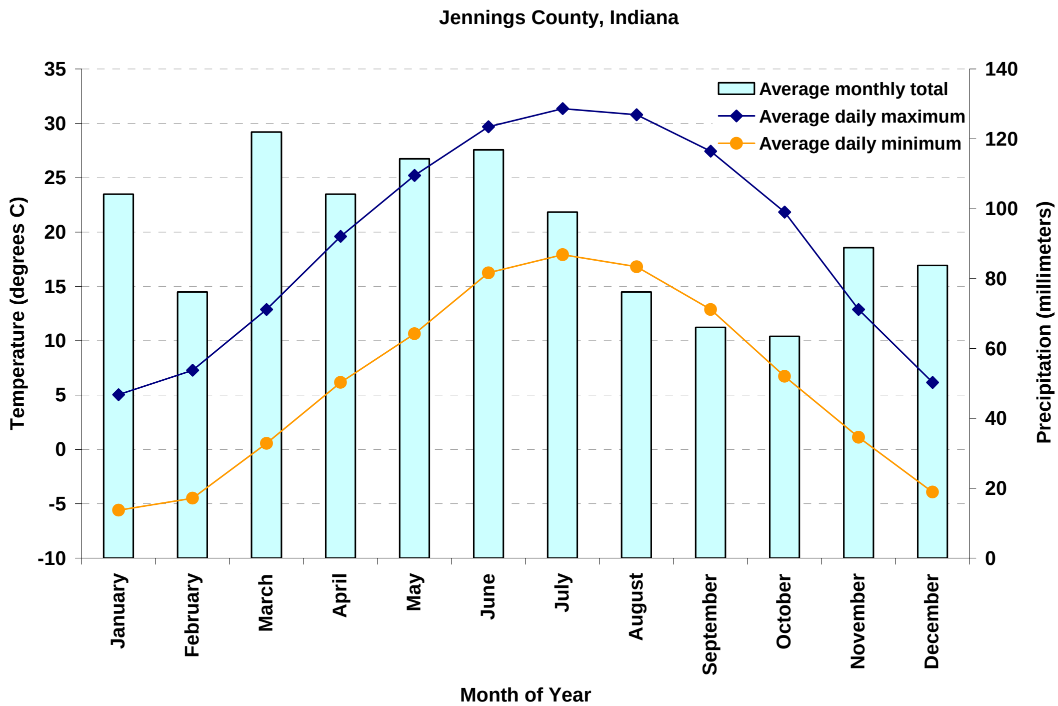
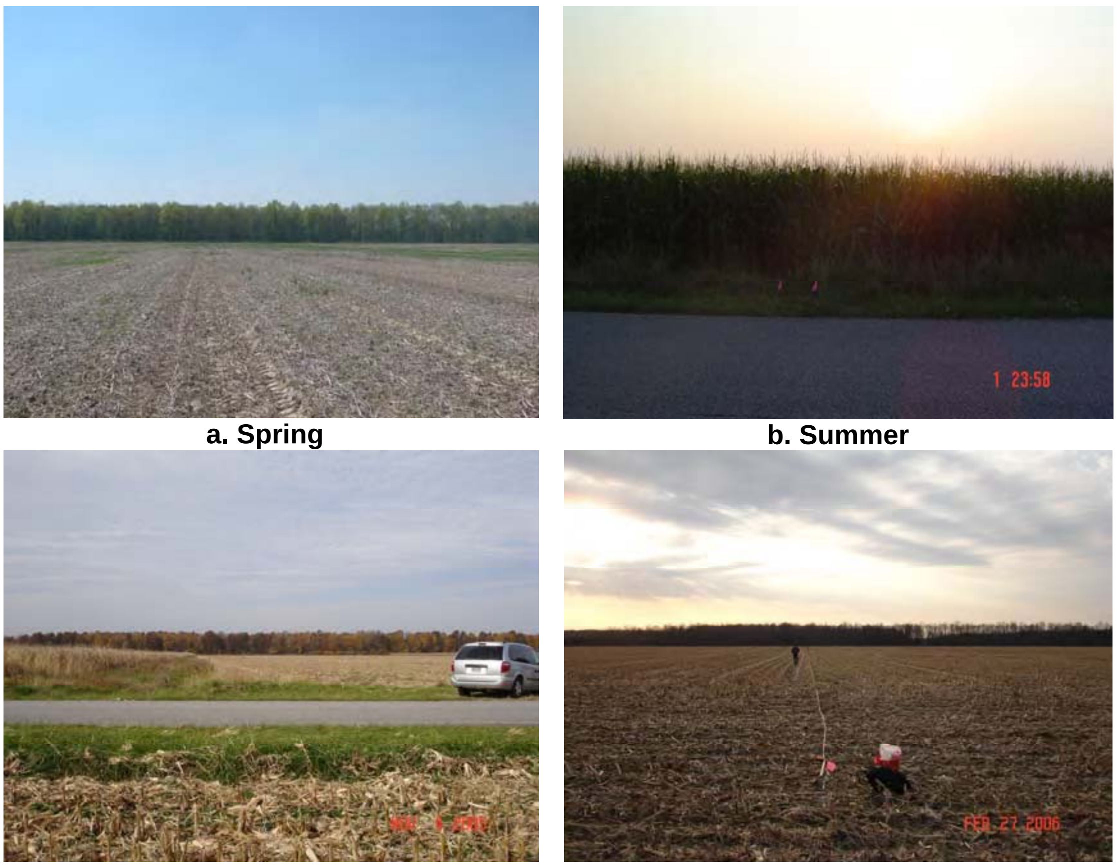


Figure 4-11. Average daily maximum and minimum temperatures, and average monthly total precipitation for Jennings County, Indiana (after Nickell 1976).

Field visits were scheduled to capture the conditions of the RAS during each season (Table 3-1). During spring IOP1, initial field measurements established a baseline of the conditions encountered. Photographs portraying the general field conditions observed during each IOP are shown in Figure 4-12, a–d. During IOP1, the field testing was conducted before any farming operations had begun because the condition of the field was too wet for the operation of farm machinery. The surface of the RAS was littered with vegetation debris from the previous planting season (Fig. 4-12a). In general, the soil conditions were moist with areas of ponded water. Once the field conditions were favorable for planting, a corn crop was planted. During summer IOP2, field measurements were taken in the corn field. The field was densely covered with vegetation, with the exception of a few bare areas near the shallow drainage ditches (Fig. 4-1). As shown in Figure 4-12b, the corn was planted up to the edge of the field. During fall IOP3, the corn field had not yet been harvested during the testing period.

Figure 4-12c shows the unharvested corn just to the north side of the RAS (left side of photo); the drainage ditch is in the center of the photo and a recently cleared field is on the right. During winter IOP4 (Fig. 4-12d), the surface of the field was again covered with debris, and the surface was damp from moisture with no large areas of ponded water.

The following sections present the findings from each seasonal IOP.



a. Spring b. Summer c. Fall d. Winter

Figure 4-12. Site conditions of North Vernon Airport RAS during each IOP: (a) spring IOP1, the view looking west from Station 300 m Centerline; (b) summer IOP2, tall corn growing in the field; the pink survey flags identify the centerline start point on the east side; (c) fall IOP3, the view north of the RAS showing unharvested and harvested corn; (d) winter IOP4, the view from RAS start point down centerline looking west.

Spring IOP1

Weather conditions during the spring IOP1 were ideal—mostly sunny during the day with warm air temperatures and a light breeze predominantly from the southwest. A rain event occurred later in the week followed by a fierce weather system containing lightning, strong winds, and hail that moved through the area late afternoon on the last day of IOP1, forcing field measurements to be suspended.

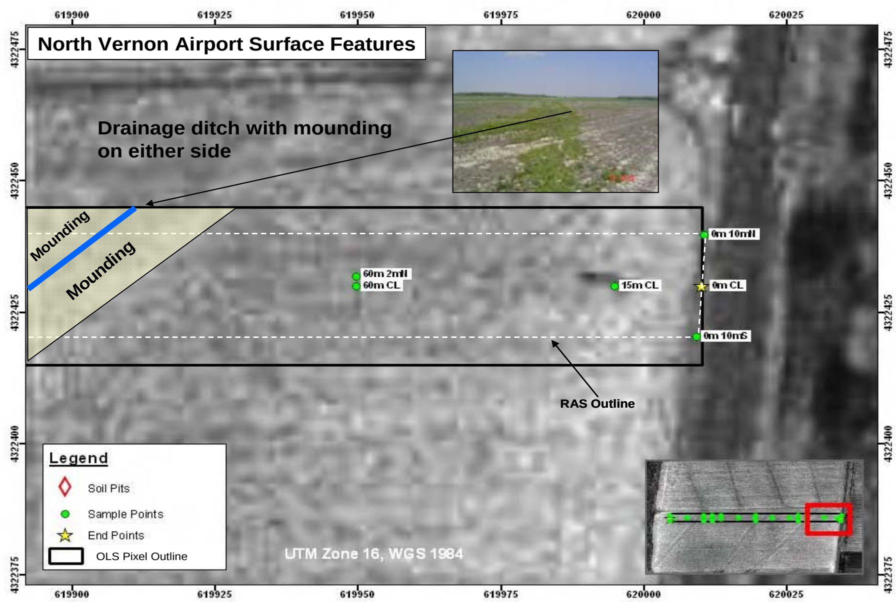
Surface condition

The surface condition is shown as a series of photographs overlaid on an orthophoto image of the RAS in Figure 4-13. The series scans the RAS from the east (beginning at Station 0 m Centerline) to the west (ending at Station 600 m Centerline). The most prominent feature on the North Vernon Airport RAS was the drainage ditch placed over large, subsurface drainage tiles, as shown in the aerial photograph in Figure 4-1. As shown in Figure 4-13, a, b, e, and f, the drainage ditches cut across the RAS between Stations 60 m and 120 m, 240 m and 300 m, and 480 m and 540 m. With the exception of the drainage ditch between Stations 480 m and 540 m, the other two ditches were flanked on either side by soil mounds, not deeper than 12 in. Water ponded on the surface in the drainage ditch between Stations 240 m and 300 m. A closer view of the surface condition at sampling Station 240 m 2 m North is shown in Figure 4-13, c and d. Also seen in Figure 4-13, c and d, are the tire imprints on the surface from farm equipment. These superficial surface marks were widespread over the RAS, and are considered an insignificant distress factor of the condition of the surface. Table 4-4 summarizes the visual surface condition.

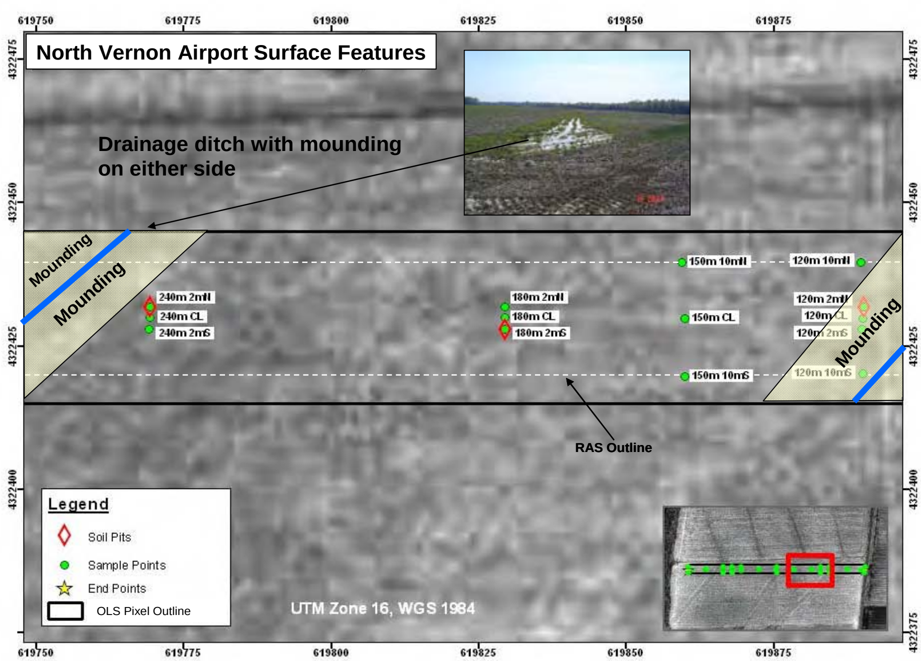
A thin layer of weathered vegetation debris covered the surface of the North Vernon Airport RAS (Fig. 4-14, a–c). The types of surface vegetation encountered during IOP1 are shown in the series of photographs (Fig. 4-14, a–c). All of the vegetation in the immediate vicinity of the RAS was low growing and under 12 in. in height. As previously mentioned, there is a border of tall deciduous trees, a distance of 30 m to the west of the RAS; this is the dark area on the left side of Figure 4-13g.

There were numerous voids (holes) on the surface of the North Vernon Airport RAS , typically 50 mm (2 in.) in diameter, extending down below the surface from crayfish mounds (Fig. 4-13e), and animal and snake bur-

rows. These features indicate the presence of soft spots, or weak areas (Air Force 2002) in the RAS. Such areas are considered high-priority test locations when assessing the structural capacity of the landing area because the strength of the soil is diminished by these voids.



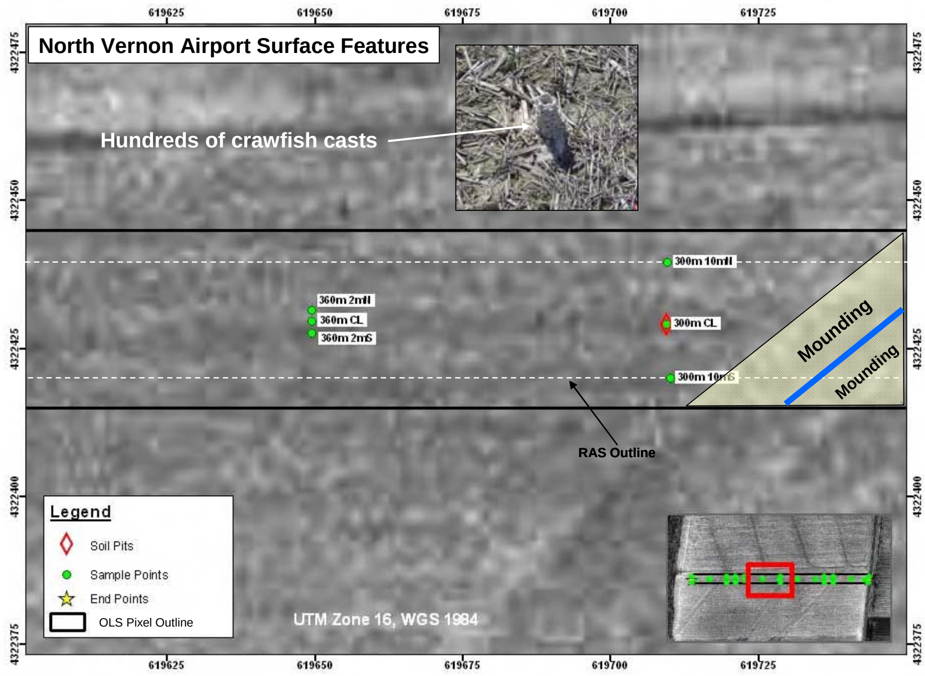
4-13 a.



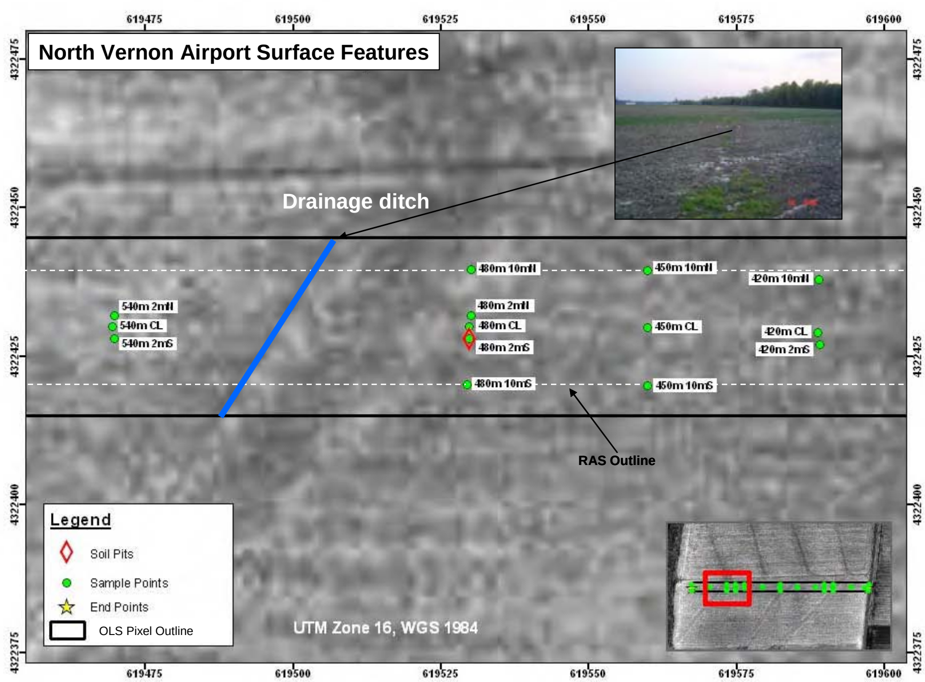
4-13 b.

4-13 c. Station 240 m 2 m North distant view looking north across transect.

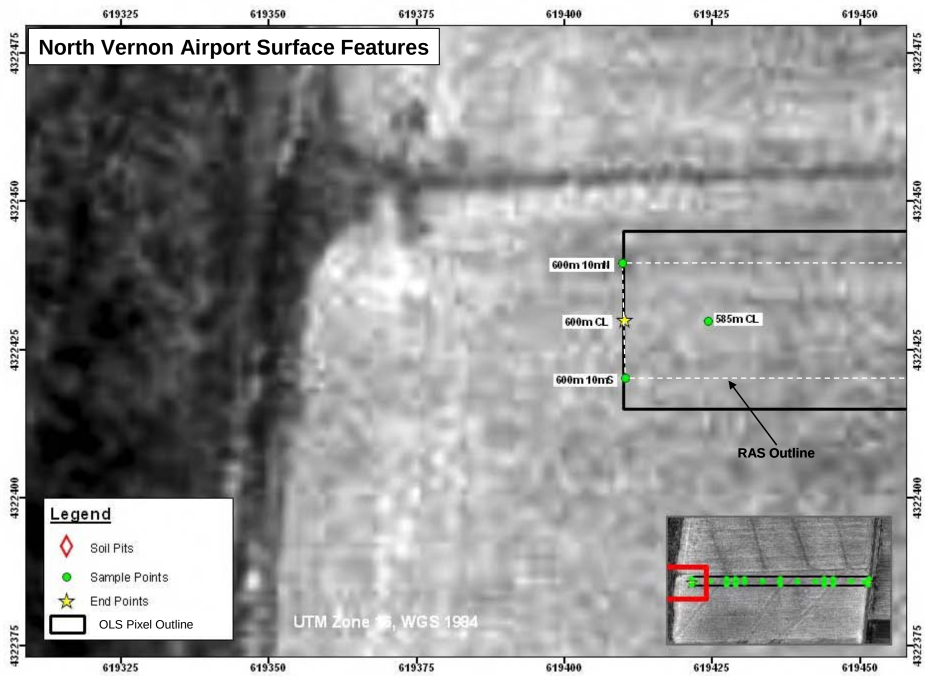
4-13 d. Station 240 m 2 m North, location of ponded water in proximity to soil pit location (lower survey flag).


North Vernon Airport Surface Features
Hundreds of crawfish casts
300m 10mN
360m 2mN
360m CL
360m 2mS
300m CL
300m 10mS
Mounding
Mounding
RAS Outline
Legend
Soil Pits
Sample Points
End Points
OLS Pixel Outline
UTM Zone 16, WGS 1984

4-13 e.


North Vernon Airport Surface Features
Drainage ditch
480m 10mN
450m 10mN
420m 10mN
540m 2mN
540m CL
540m 2mS
480m 2mN
480m CL
480m 2mS
450m CL
420m CL
420m 2mS
480m 10mS
450m 10mS
RAS Outline
Legend
Soil Pits
Sample Points
End Points
OLS Pixel Outline
UTM Zone 16, WGS 1984

4-13 f.

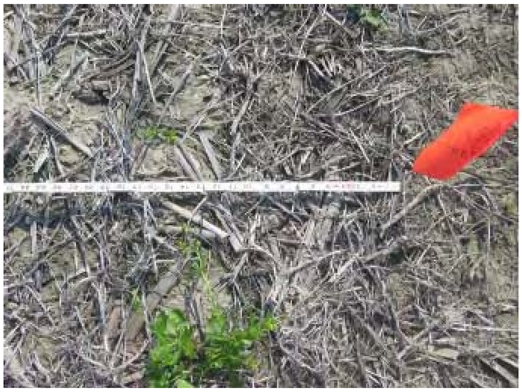


4-13 g.

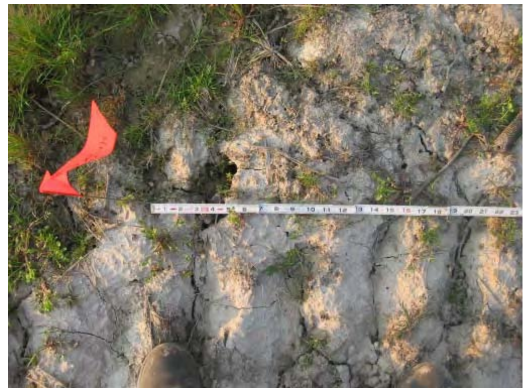
Figure 4-13. Surface condition for North Vernon Airport RAS.

Table 4-4. North Vernon Airport RAS surface features from spring IOP1.

	Distress Types	Condition	Comments
1.	Potholes or depressions	Present, 12-in. wide by several inches deep	Surface drainage ditches
2.	Ruts	Present, 2–3 in. deep	Tire tracks from farm equipment
3.	Corrugations		Did not see any
4.	Rolling resistance material (RRM)		Did not see any loose material
5.	Loose aggregate		Not applicable
6.	Dust	Low severity	
7.	Layer failure		Not applicable
8.	Vegetation	Low growth	Wild onions and low growing vegetation less than 1-ft high
9.	Standing water / wet areas	Ponded water in vicinity of Station 240 m	
10.	Rock outcropping		Not applicable
11.	Snow		Not applicable
12.	Other	1.Voids due to crayfish and snakes suggest weak areas 2. Vegetation debris	



4-14 a. *Ranunculus acris*.



4-14 b. The grass under the ruler is *Paspalum setaceum*. *Poa compressa* is in the upper right corner. *Ranunculus acris* and *Agropyrn repens* have also been identified.

4-14 c. Field garlic (*Allium vineale*) is in the foreground. *Ranunculus acris* is the yellowish flowering plant. *Agropyrn repens* is in the background.

Figure 4-14. North Vernon Airport RAS vegetation species.

Soil moisture

During the spring IOP1, soil moisture measurements were made with depth as each soil pit was excavated. The same soil samples collected for laboratory analysis also provided gravimetric soil moisture contents. The ML2 probe was used to take readings on the surface and at depths of 75, 150, 300, 450, and 600 mm (3, 6, 12, 18, and 24 in.) below the surface. For readings taken at 300 and 600 mm (12 and 24 in.), the probe was inserted into the bottom of the soil pit. For the remaining readings, the probe was inserted into the sidewall of the soil pit. A set of three readings was taken at each depth. During IOP1, only the volumetric moisture content was recorded. During subsequent field visits, the millivolt values were also recorded. To reduce the measurement error, additional readings were taken when there was a difference of 3%. The median volumetric moisture content was determined from each set of readings; no data were discarded. Table B-2 in Appendix B lists the readings and the median values from spring IOP1.

Figure 4-15 plots the moisture content with depth in each soil pit. As shown on the chart, the moisture content in the upper 150 mm (6 in.) of soil ranges from 28% to 31%. Below this depth, the moisture content trend clearly increases with depth. Water was encountered at the bottom of the soil pit, 600 mm (24 in.) below the surface. A volumetric moisture content reading of 42% was determined to be saturated. It is possible that trapped air may have occupied approximately 3% of the sample volume when the measurement was taken (S. Grant, personal communication, 2006). The median moisture content at each depth in each soil pit is plotted in Figure 4-16. The median values of all of the moisture measurements taken at each depth at all of the soil pits are given in Table B-2 in Appendix B. These values are represented on the chart as the solid line through the data points in Figure 4-16.

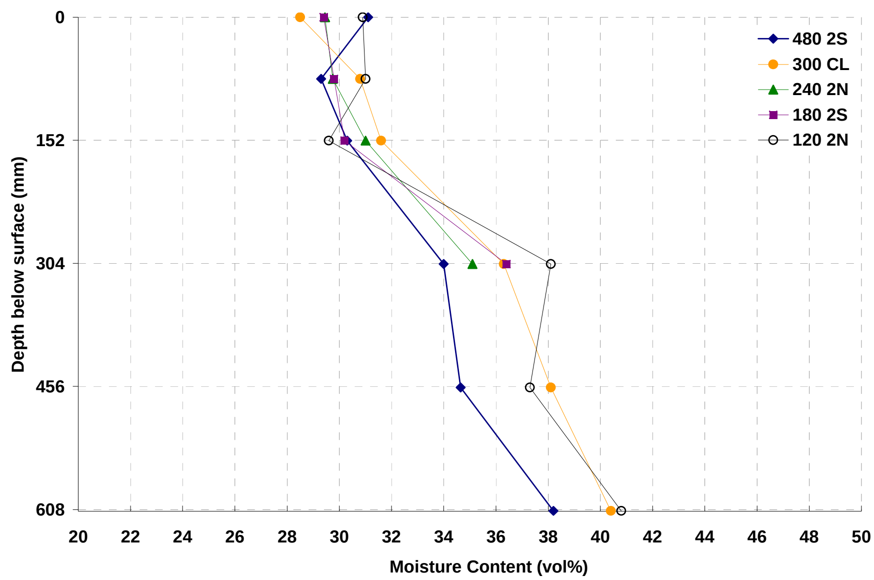


Figure 4-15. North Vernon Airport RAS average volumetric moisture content readings with depth for all soil pit locations, spring IOP1.

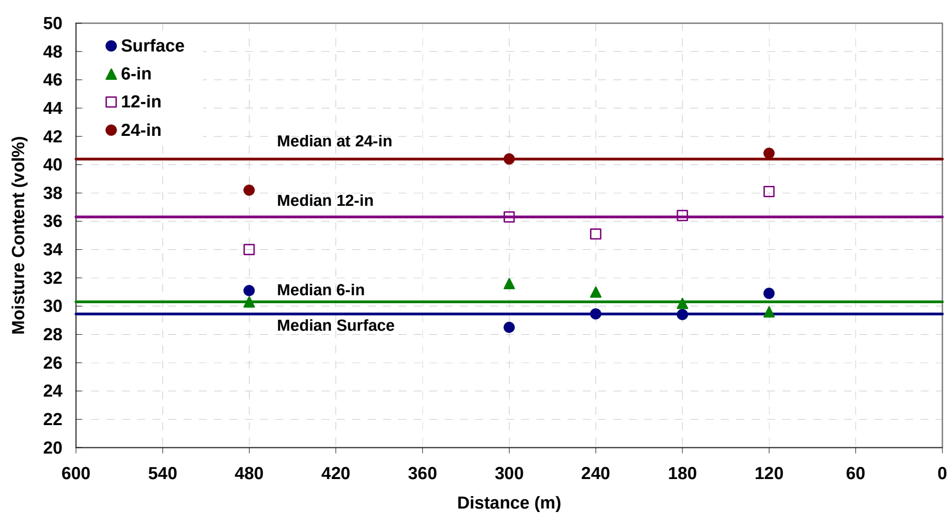


Figure 4-16. North Vernon Airport RAS spring IOP1 median volumetric moisture readings.

Soil strength

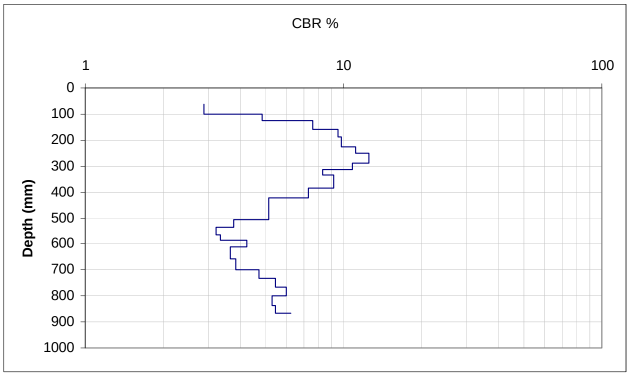
Soil strength profiles were measured using the DCP and the cone penetrometer during the spring IOP. Seventeen DCP tests were conducted on the RAS, including along the edge, 10 m north and south of the RAS centerline, and within 1 m of the locations of the soil pits. Near the soil pit at sampling Stations 420 m 2 m South and 480 m Centerline, the DCP began sinking into the soil under its own weight at depths of 940 mm (37 in.) and 790 mm (31 in.), respectively. The test was repeated at sampling Station 480 m Centerline.

Table 4-5 summarizes the DCP testing during the spring IOP of the average CBR values at depths of 300–600 and 600–900 mm below the surface. Note in Table 4-5 the series of test points from sampling Station 240—420 m with average CBR values of 2 and 3. The weak locations are the controlling factor on the airfield, and this series of sampling locations indicates a very weak layer. Similarly, at the depth of 600–900 mm below the surface, the data also indicate weak CBR values of 2 and 3 between sampling Stations 360 and 420 m. DCP strength profiles for sampling stations along the RAS centerline are shown in Figure 4-17, a–e.

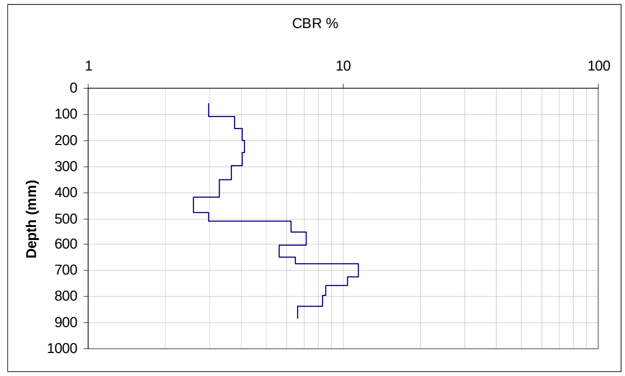
A rain event occurred during the early morning before the cone penetrometer measurements were made. The soil was wet from the precipitation, and because the surface condition had changed, a surface moisture reading was taken using the Dynamax ML2 moisture probe in the same location as the cone penetrometer readings were taken. The cone penetrometer and moisture probe data are given in Table B-3, Appendix B.

Table 4-5. North Vernon Municipal Airport summary of DCP test results from spring IOP1.

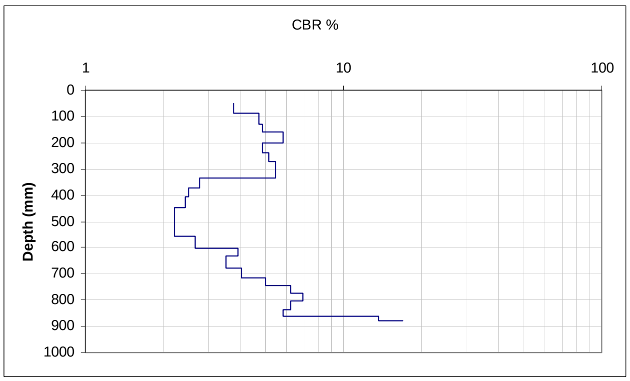
Station	Date	Average CBR within 15-cm Bins							Average CBR within 30-cm Bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
0 m Centerline	4/19/2005	5	11	8	4	4	6		9	6	5	
120 m Centerline 10 m North	4/19/2005	2	6	4	3	2	3		4	3	3	
120 m Centerline 10 m South	4/19/2005	4	6	4	6	6	3		5	5	4	
120 m Centerline (pit was north)	4/19/2005	3	4	3	5	8	8		4	4	8	
180 m Centerline 2 m North	4/19/2005	3	7	6	6	6	6		5	6	6	
240 m Centerline 2 m North	4/19/2005	2	4	3	2	5	8		3	3	7	
240 m Centerline 2 m South	4/19/2005	4	3	3	2	4	6		3	3	5	
300 m Centerline	4/19/2005	4	5	2	2	5	10		5	2	7	
360 m Centerline 2 m North	4/19/2005	4	6	4	2	2	3		5	3	3	
420 m Centerline 2 m South	4/19/2005	4	7	4	2	2	2		5	3	2	
480 m Centerline 10 m North	4/19/2005	5	5	14	7	2	3		5	11	3	
480 m Centerline 10 m South	4/19/2005	3	7	10	6	4	4		5	9	4	
480 m Centerline	4/19/2005	3	5	6	2	2	1		5	4	2	
480 m Centerline	4/19/2005	4	6	7	6	6	5		5	6	5	
540 m Centerline 2 m South	4/19/2005	4	4	1	3	3	3		4	3	3	
60 m Centerline 2 m North	4/19/2005	3	4	4	3	1	2	3	4	4	2	3
600 m Centerline	4/19/2005	4	8	4	3	5	9		7	3	7	



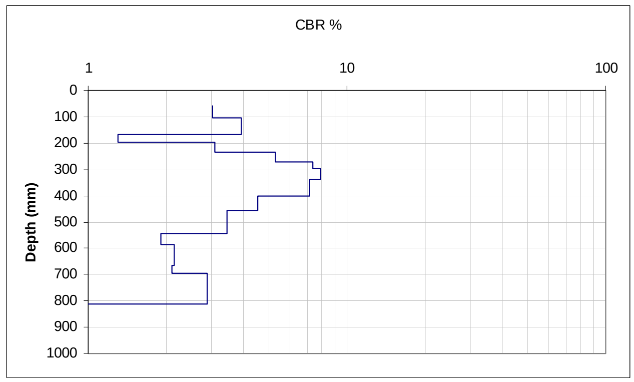
4-17 a. Station 0 m Centerline.



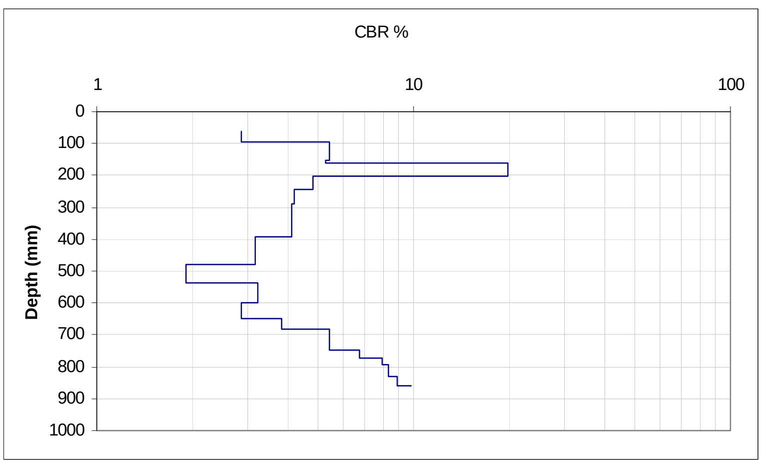
4-17 b. Station 120 m Centerline.



4-17 c. Station 300 m Centerline.



4-17 d. Station 480 m Centerline.



4-17 e. Station 600 m Centerline.

Figure 4-17. North Vernon Municipal Airport spring IOP1 DCP strength profiles.

The cone penetrometer data report a cone index (CI) value. Using the relationship in Equation 3-3, a CBR value was calculated. Figure 4-18 shows the calculated CBR values for both the upper 150 mm (6 in.) and 150–300 mm (6–12 in.) along the RAS.

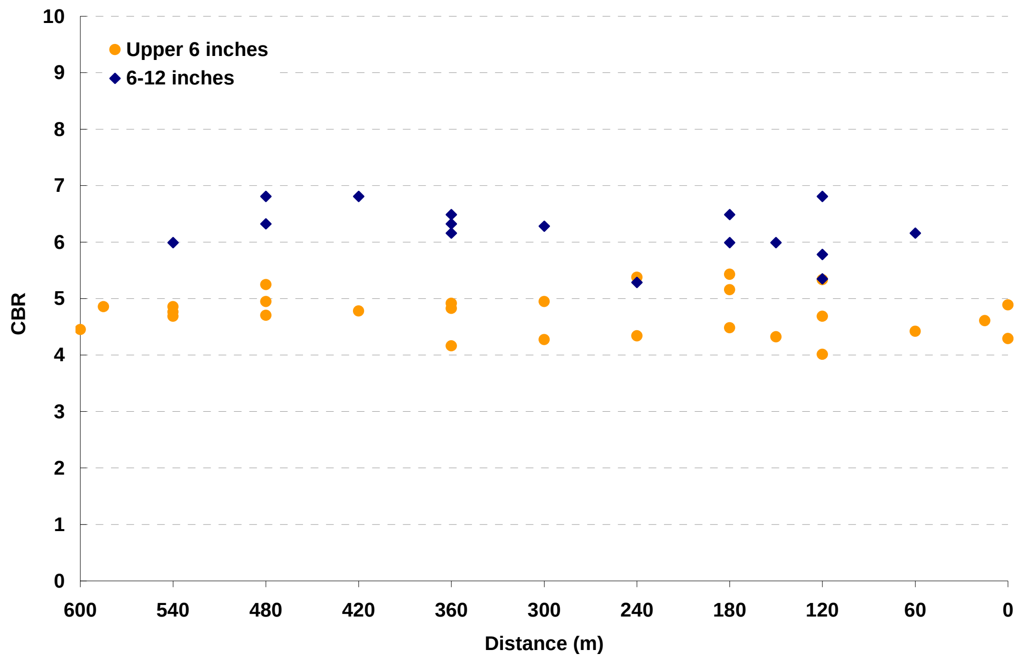


Figure 4-18. Calculated upper soil strength values along the North Vernon Airport RAS spring IOP1.

Organic content

Organic content testing was completed in the ERDC-CRREL soils laboratory using surface soil samples collected during the spring IOP. Samples tested from the North Vernon Airport RAS are listed, along with the results, in Table 4-6. Replicate samples were run on samples collected at 120 m 2 m North and 300 m Centerline.

Summer IOP2

This section describes the conditions of the North Vernon Airport RAS encountered during the summer IOP2 that occurred in early August 2005. Weather conditions during the summer IOP2 were sunny, hot, and humid. Daytime temperatures were in the 90s.

Surface condition

A corn crop, approximately 2.4-m (8-ft) high, was growing on the RAS during the summer IOP2. The rows of corn ran in an east-west direction, approximately parallel to the centerline of the RAS. The field was densely planted, with the exception of a couple of bare areas near the surface drainage ditches, with the rows being roughly 3-ft apart (Fig. 4-19). The soil surface was dry, and in some areas cracked. In evaluating the surface condition for a runway the presence of the corn greater than 12-in. tall would make the rating condition of the RAS unsatisfactory.

Table 4-6. North Vernon Municipal Airport organic samples tested.

Sample Station	IOP Collected	Wet Wt. (g)	Tare (g)	Dry Wt (g)	Dry Soil (g)	Water (g)	Moisture Content (%)	Post-Furnace Wt (g)	% Ash	% Organic	Average of Replicates
Airport 0 10 N	Summer	130.47	67.38	128.08	60.70	2.39	3.94	126.08	98.44	1.56	
Airport 120 2 N	Spring	121.08	67.48	109.27	41.79	11.81	28.26				
Airport 120 2 N (replicate)	Spring	164.13	82.95	146.83	63.88	17.30	27.08	145.05	98.79	1.21	
Airport 120 2 N (replicate)	Spring	198.07	137.20	185.08	47.88	12.99	27.13	183.76	99.29	0.71	0.96
Airport 180 2 S	Spring	208.18	137.20	193.27	56.07	14.91	26.59	191.68	99.18	0.82	
Airport 240 2 N	Spring	198.50	137.21	197.57	60.36	0.93	1.54	195.09	98.74	1.26	
Airport 240 CL	Summer	116.35	68.58	115.42	46.84	0.93	1.99	113.76	98.56	1.44	
Airport 300 CL	Spring	114.52	64.24	107.54	43.30	6.98	16.12	107.17	99.66	0.34	
Airport 300 CL (replicate)	Spring	107.35	64.55	101.59	37.04	5.76	15.55	100.25	98.68	1.32	
Airport 300 CL (replicate)	Spring	122.07	73.16	115.31	42.15	6.76	16.04	113.77	98.66	1.34	1.00
Airport 480 2 S	Spring	120.12	67.14	108.76	41.62	11.36	27.29	108.02	99.32	0.68	
Airport weather station	Fall	123.46	68.58	114.03	45.45	9.43	20.75	112.85	98.97	1.03	

Figure 4-19. North Vernon Airport RAS during summer IOP2. The surface of the soil is dry and cracked. Note the density of the vegetation.

Soil moisture

Soil moisture and soil strength measurements made during the summer IOP were spatially distributed across the surface of the RAS. Instead of digging soil pits, a gas-powered auger with a 4-in. bit was used to drill holes to three target depths into the soil. Measurements were made on the surface, and at depths of 300, 600, and 760 mm (12, 24, and 30 in.) below. The Dynamax ML2 moisture probe was placed down the hole to take moisture measurements (Fig. 4-20). Due to the configuration of the auger bit, loose soil remained at the bottom of the hole, despite efforts to remove it by hand. This is the reason for some variation in the depths where the readings were made.

The moisture content data and median values are given with the corresponding depths in Table B-4, Appendix B. These values and the median moisture readings at each sampling station are plotted in Figure 4-21. The data points at the surface and 12-in. depths are more scattered around the median values from sampling Station 0 to about the center of the RAS, at 300 m. Overall, the median moisture contents decreased at all depths by 57% at the surface and 12 in., and 46% at 24 in.

Figure 4-20. Taking soil moisture readings with a Dynamax ML2 in the auger hole (North Vernon Airport RAS, summer IOP2).

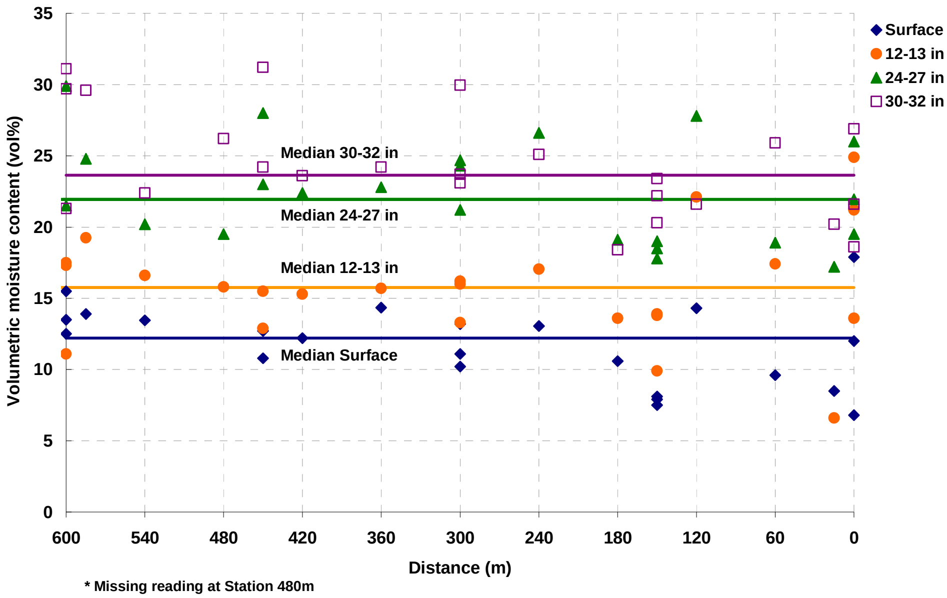


Figure 4-21. Summer IOP2 median moisture content.

Soil strength

In addition to the soil moisture measurements, soil strength measurements were a main priority during the summer IOP. The primary tools used were the DCP for the strength profile, and the lightweight Clegg hammer for the upper surface strength. Twenty-seven sampling stations were tested along the RAS centerline and either 10 m north or south. There was one repeat test at Station 480 m 10 m South.

Table B-5 in Appendix B gives a summary of the DCP test results, converted to CBR values. The maximum 48 CBR reading was measured at Station 480 m; however, all of the remaining readings are 34 CBR or less. It is likely that the high reading of 48 CBR may be due to hitting a rock. The median value of all of the data points is 16 CBR. Although the median value is 4 times larger than the spring IOP1 median value, there are still weak points on the RAS that will control how the RAS is evaluated during this season, particularly along the centerline stations. Station 120 m Centerline is one such location with CBR 6 strength in the upper 600 mm. Also of note is the CBR 2 at a depth of 600–900 mm at Station 240 m Centerline. At this depth, this is the weakest point on the RAS, with many other stations along the centerline reporting values of only 3 or 4 CBR at depths greater than 600 mm.

All of the upper soil strength measurements were made using a lightweight Clegg hammer. Clegg soil strength measurements were taken at 28 sampling locations distributed spatially across the RAS. The unevenness of the surface made readings difficult. At each sampling location, readings were taken at three test points. The Clegg hammer data, along with both the average and median CBR values, are given in Table B-6 in Appendix B. The blank cells under the “Calculated CBR” heading indicate raw data that did not increase with each drop of the hammer (the exception being if the decrease in the CI value was only 0.1). In this case, the CBR was not calculated and used to determine either the average or the median.

Summer organic content

Two surface soil samples were collected for organic testing during the summer IOP. These samples were collected at Stations 0 m 10 m North and 240 m Centerline. The test results are shown in Table 4-6. No replicates were run for either of these samples.

Fall IOP3

During IOP3, the corn had not been harvested and was dried on the stalk. A light rainfall the day before field testing moistened the soil surface. A total of 31 sampling stations were tested during IOP3 (Table B-1, Appendix B). Soil strength measurements were taken with the DCP, and upper soil strength using the lightweight Clegg hammer and the cone penetrometer. Soil moisture measurements were taken using the Dynamax ML2 probe. To verify the soil density measurements, soil pits were excavated near four of the initial soil pit locations (spring IOP1) at 120 m 2 m North, 180 m 2 m South, 300 m Centerline, and 480 m 2 m South. Density measurements were made with depth using the Troxler nuclear gauge and the drive cylinder method. The soil samples collected from the drive cylinders were analyzed in the laboratory. It turns out that the drive cylinder method is not useful in fine-grained soil, such as that in Indiana (as explained in "Non-seasonal conditions").

Surface condition

The outstanding feature from the fall IOP was the dried corn stalks, roughly 6-ft tall, covering the field. This type of distress would likely be considered unsuitable for aircraft operations (Fig. 4-22). Close to the soil surface was low-growing vegetation (Fig. 4-23). The greater portion of any area on the RAS was covered with a combination of dried or low-growing vegetation, as shown in Figure 4-23. The only areas where bare soil was exposed were near the drainage ditches. The combination of low-growth vegetation and debris on the surface were a hindrance when taking surface strength measurements with the Clegg hammer. At the end of the fall IOP3, large harvesting equipment was used to cut the corn stalks and harvest the corn. Figure 4-24 shows the condition of the field after harvesting, with rows of stubble approximately 300–400 mm (12–16 in.) high (this field was across the street on the east end of the RAS); Figure 4-25 is a close-up photo of the surface, showing the large pieces of debris left after harvesting.

Soil moisture

Soil moisture measurements collected during the fall IOP used two methods: the ML2 probe was used to obtain volumetric moisture readings spatially distributed with depth (similar to the approach used during the summer IOP2 using the auger and 4-in. bit); and soil samples, via the

drive cylinder method, were collected from three soil pit locations for gravimetric moisture content values.

For the volumetric moisture contents, the target reading depths were the surface, and at depths 150, 300, 600, and 750 mm (6, 12, 24, and 30 in.) below the surface. A total of 29 stations were sampled, including 15 stations along the RAS centerline and 14 stations 10 m off of centerline on both the north and south edges of the RAS. Both the average and median readings are listed in Table B-7 in Appendix B.

The median values are plotted in Figure 4-26. The median (32.6%) for the surface readings was high due to the rainfall received on the previous day. Still, the median moisture content of the surface was approximately 4% higher than the median values at both the 12- and 24-in. depths, which were the same at 28.7%. Because the median value at the 6-in. depth was very similar (28.5%), the median was not included on the plot. At the 30-in. depth, the median value was 32.4%. No clear trends are present in the data points; they appear to scatter around the median values at each depth. This shows that the moisture content was consistent throughout the soil layers with both the uppermost (surface) and the deepest 750-mm (30-in.) layers having higher moisture contents. The increased soil moisture was visible in the soil cuttings as the hole was drilled with the auger. As may be seen in the photograph of Figure 4-22, the cuttings clumped together.

Four soil pits were excavated, near the locations of the soil pits excavated during the spring IOP1 (Fig. 3-2). Soil samples were collected using the drive cylinder method, as previously described in the “Nonseasonal conditions—Soil density” section. The soil pit at 300 m Centerline was excavated down to 900 mm below the surface. The gravimetric moisture contents with depth, as determined in the laboratory, are plotted in Figure 4-27.

Figure 4-22. North Vernon Airport RAS fall IOP3 sampling station showing dried cornstalks, surface vegetation, and auger hole for soil moisture measurements (foreground).

Figure 4-23. North Vernon Airport RAS fall IOP3 sampling station showing vegetation and auger hole for soil moisture measurements.

Figure 4-24. North Vernon Airport RAS rows of stubble after harvesting, fall IOP3.

Figure 4-25. North Vernon Airport RAS close-up of surface, fall IOP3.

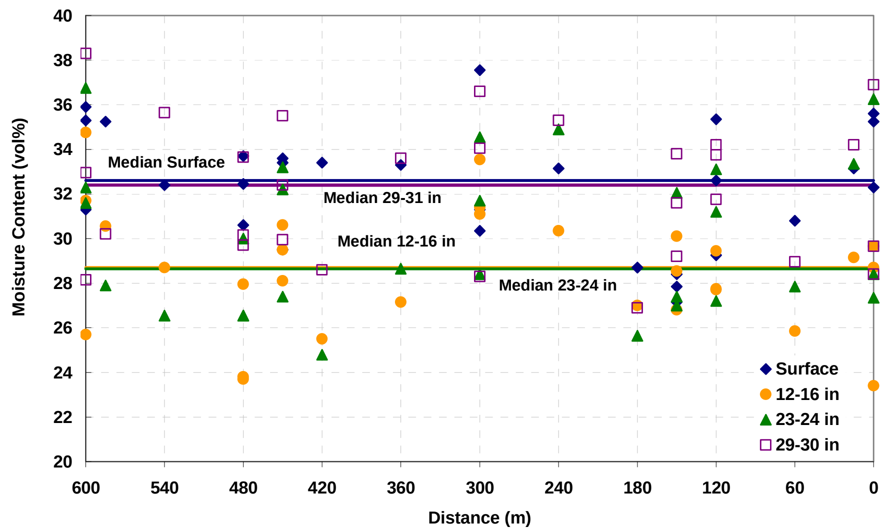


Figure 4-26. North Vernon Airport RAS fall IOP3 median moisture values.

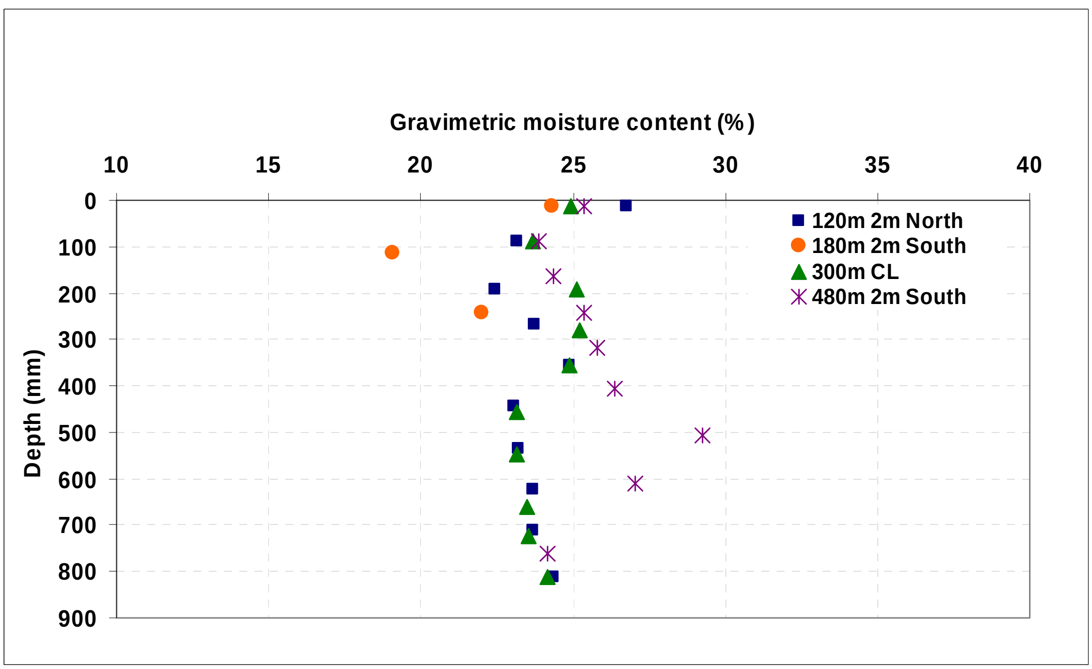


Figure 4-27. North Vernon Airport RAS gravimetric moisture content values from soil pits.

Soil strength

A total of 31 sampling stations were tested during the fall IOP3 (binned CBR data are shown in Table B-8, Appendix B). Overall, the median CBR value for all of the DCP test points decreased substantially from the summer IOP by more than 50%, down to 7. The standard deviation is 3. The CBR values along the RAS centerline ranged from a low of 2 (Station 360 m Centerline, 900- to 1,200-mm depth) to 13. At different depths, the layers had varying strengths. In general, the soil strength decreased with depth.

For the surface strength, three instruments were used: the lightweight Clegg hammer, a cone penetrometer, and the Dor-Cone. Because this was the only IOP that used the DOR-cone and there are no other seasons with which to compare these data, these data will not be considered for further analysis. The average cone penetrometer readings and calculated CBR values are given in Table B-9, Appendix B. Clegg hammer readings, calculated CBR, averages, and median CBR are given in Table B-10, Appendix B.

Organic content

Only one organic sample was collected at the weather station during the fall IOP (Table 4-6).

Winter IOP4

Surface condition

The surface of the soil was wet. In some places where the moisture content was very high, it was slippery. Vehicle traffic on the surface was prone to getting stuck, more from lack of track rather than sinking into soft soil. Figures 4-28 and 4-29 show the general surface conditions during IOP4.

Soil moisture

During the winter IOP4, soil moisture measurements were made using the Dynamax ML2 by taking readings with depth down auger holes. Measurements were made at 19 sampling stations, with 13 located along the centerline of the RAS, and the remaining six taken along both the north and south edges of the RAS at Stations 0, 300, and 600 m.

The photograph in Figure 4-30 shows an example of the moisture on the surface. Moisture content data and median values are given in Table B-11, Appendix B. The median values at depth are plotted in Figure 4-31. Note that the median moisture content for all of the layers, with the exception of 11–14 in. below the surface, are consistently near a 40% volumetric moisture content. At the 12-in. depth, the data points trend in a convex pattern, with the ends of the RAS being slightly drier than the center, where the highest moisture content was measured. The data points at the other depths tend to be scattered around the median value.

Field notes taken during the IOP observe instances where water was visible in the auger hole. This was noted at six sampling stations, particularly at deeper depths (such as 600–750 mm [24—30 in.] below the surface). At sampling Station 300 m Centerline, water at the bottom of the auger hole was noted at all three sampling stations, 300 Centerline, 10 m North, and 10 m South at depths of 23, 32, and 24 in. respectively. At sampling Station 600 m Centerline, sticky mud was noted at a depth of 25 in. below the surface.

Soil strength

Again the DCP was used to measure the soil strength profile during this IOP. Nineteen sampling stations were tested, primarily along the RAS centerline. The edges of the RAS (10 m either north or south) were sampled only at three stations: 0, 300, and 600 m. Data were recorded using an automatic data acquisition system made by Vertek. Manual DCP measurements were made at several locations to compare the readings between the manual and automatic methods. The CBR values determined from both the automatic and manual readings compare within a difference of one CBR unit (Table B-12, Appendix B).

Soil organic content

No organic content samples were collected during the winter IOP.

Figure 4-28. View looking down centerline from Station 600 m at North Vernon Airport RAS, winter IOP3.

4-29 a. North.

4-29 b. West.

4-29 c. South.

4-29 d. East.

Figure 4-29. Surface coverage photographs around North Vernon Airport RAS, Station 300 m Centerline survey flag, during winter IOP4; (a) north, (b) west, (c) south, and (d) east.

Figure 4-30. North Vernon Airport RAS surface moisture during the winter IOP4.

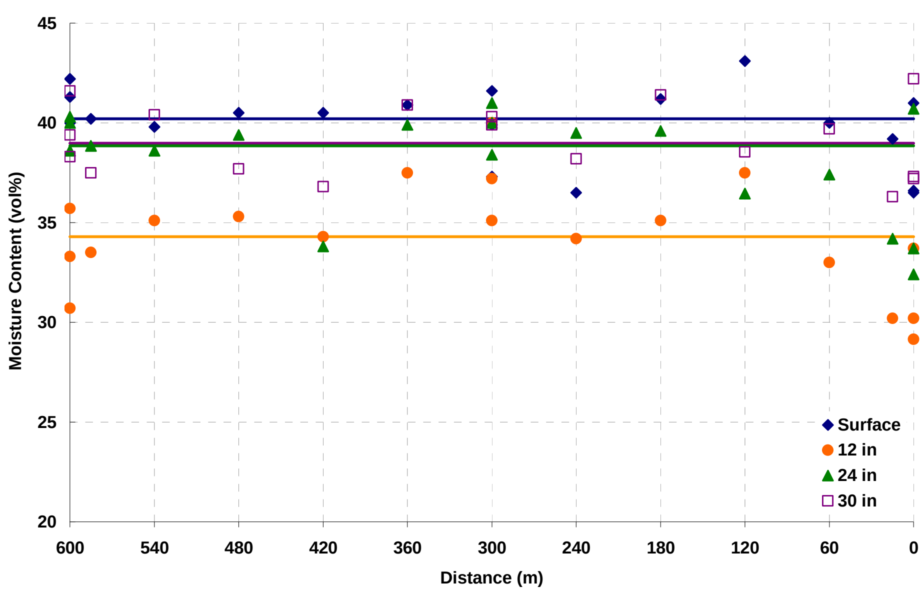


Figure 4-31. North Vernon Airport RAS winter IOP4 median moisture values.

4.4 Seasonal discussion

Surface condition

On the ground at the North Vernon Airport RAS, there were numerous surface voids from burrows. This weakens the upper layer, making it unacceptable for aircraft operations. It is, therefore, important to establish whether the OLS software can evaluate this type of deficiency.

Soil moisture

In looking only at the median volumetric moisture content readings with depth from the Dynamax ML2 probe for each season (Table 4-7; Fig. 4-32), the plot clearly shows that the moisture content was elevated during the spring, fall, and winter seasons. Only the summer season shows a decrease in the soil moisture content, however, the median moisture content is increasing with depth.

The volumetric and gravimetric moisture content values cannot be directly compared because they are not the same thing. A soil sample is composed of soil, water, and air. This aggregation of materials in solid, liquid, and gas form may be illustrated using a three-phase diagram, a fundamental tool in geotechnical engineering. Typically, when the density is known, the user may convert from mass-based information on one side of the diagram to volumetric descriptors on the other, and vice versa. Use of the measured density readings (see “Nonseasonal conditions”) with the gravimetric moisture content yielded a volumetric moisture content value at a specific depth.

The gravimetric moisture contents in Table 4-8 were used to calculate a volumetric moisture content. The calculated volumetric moisture content was compared to the measured volumetric moisture content from the Dynamax ML2 (referred to as ML2 in the figure) probe (Fig. 4-33, a–f). During the spring IOP1, the ML2 readings were taken in the soil pit as the soil samples used for the gravimetric moisture contents were collected; in essence the readings were taken side-by-side. Error bars of ±6.0% have been added to the plots because this is the expected error measurement range for the ML2 probe (Delta-T Devices 1999).

During the spring IOP1, the ML2 moisture content readings compare well with the calculated volumetric moisture content values. With the exception of two points, all of the data points fall within the 6% error range. Interestingly, all of the ML2 readings are higher than the calculated volumetric readings during the spring IOP1. This suggests that the volumetric moisture content values are good within 6%.

Table 4-7. North Vernon Airport RAS volumetric soil moisture content summarized by season.

Median moisture content values by season							
Spring		Summer		Fall		Winter	
Depth	Vol%	Depth	Vol%	Depth	Vol%	Depth	Vol%
(in.)	Spring	(in.)	Summer	(in.)	Fall	(in.)	Winter
Surface	29.5		12		32.6		40
3	29.8						
6	30.3				28.5		
12	36.3	12–13	16	12–16	28.7	11–14	34.3
18	37.3						
24	40.4	24–27	22	23–24	28.7	22–25	38.9
30	NA	30–32	24	29–32	32.4	29–30	39

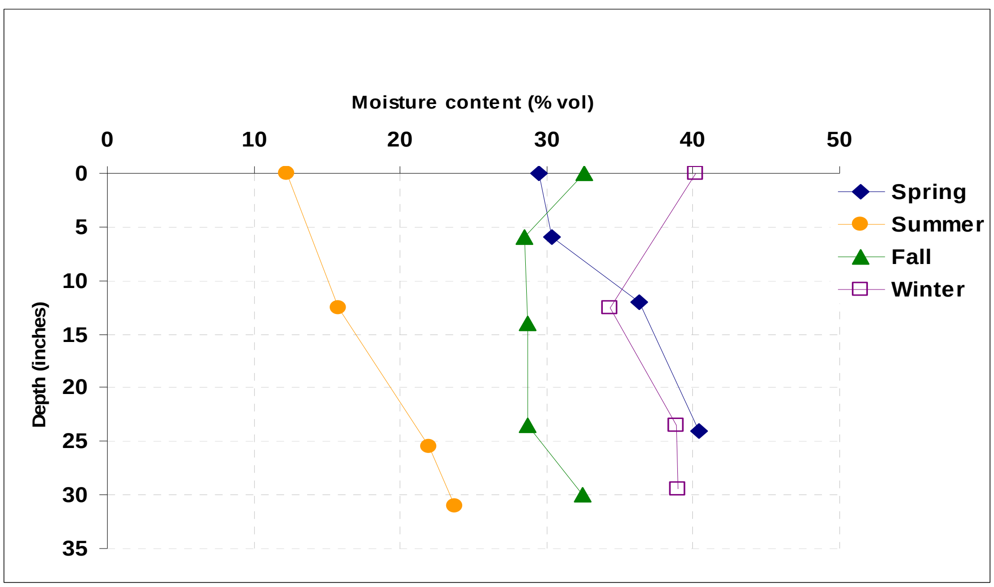
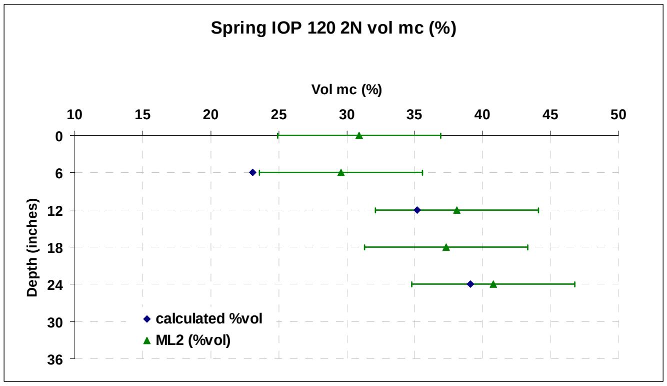


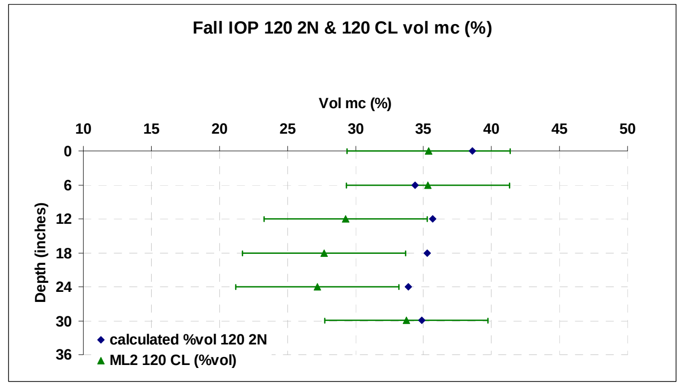
Figure 4-32. Summary of median volumetric moisture content values with depth for all IOPs.

Table 4-8. North Vernon Airport RAS gravimetric soil moisture content summarized by soil pit location.

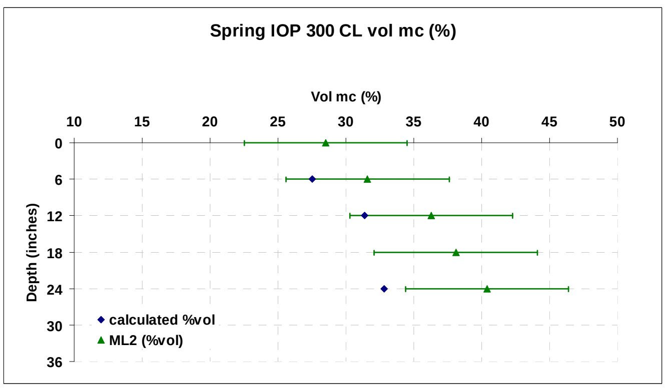
120m 2m North				180m 2m South				300m Centerline				480m 2m South			
Spring		Fall		Spring		Fall		Spring		Fall		Spring		Fall	
Depth (inches)	water content (% dry weight)	Depth (inches)	water content (% dry weight)	Depth (inches)	water content (% dry weight)	Depth (inches)	water content (% dry weight)	Depth (inches)	water content (% dry weight)	Depth (inches)	water content (% dry weight)	Depth (inches)	water content (% dry weight)	Depth (inches)	water content (% dry weight)
1-6	22.4	0.5 - 3.5	26.7			0.5 - 3.5	24.3	1-6	19.4	0.5 - 3.5	24.9	1-6	19.9	0.5" - 3.5"	25.4
12	23.1	3.5 - 6.5	23.1			4.5 - 7.5	19.1	12	19.9	3.5 - 6.5	23.7	12	20.5	3.5" - 6.5"	23.8
24	26.8	7.5 - 10.5	22.4			9.5 - 12.5	22.0	24	22.4	7.5 - 10.5	25.1	24	24.3	6.5" - 9.5"	24.4
		10.5 - 13.5	23.7							11 - 14	25.2			9.5" - 12.5"	25.4
		14 - 17	24.9							14 - 17	24.9			12.5" - 15.5"	25.8
		17.5 - 20.5	23.1							18 - 21	23.1			16" - 19"	26.4
		21 - 24	23.2							21.5 - 24.5	23.2			20" - 23"	29.3
		24.5 - 27.5	23.7							26 - 29	23.5			24" - 27"	27.0
		28 - 31	23.7							28.5 - 31.5	23.6			30" - 33"	24.1
		32 - 35	24.4							32 - 35	24.2				



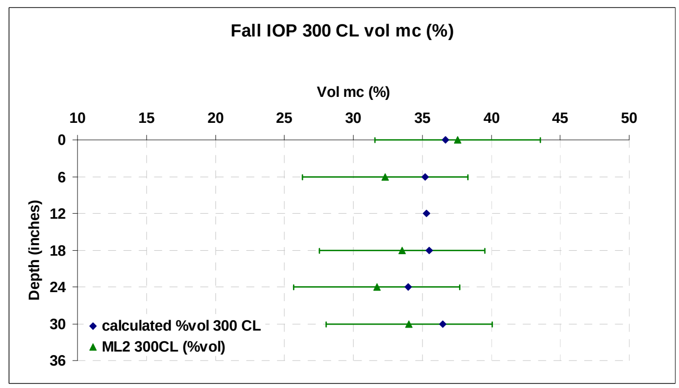
4-33 a.



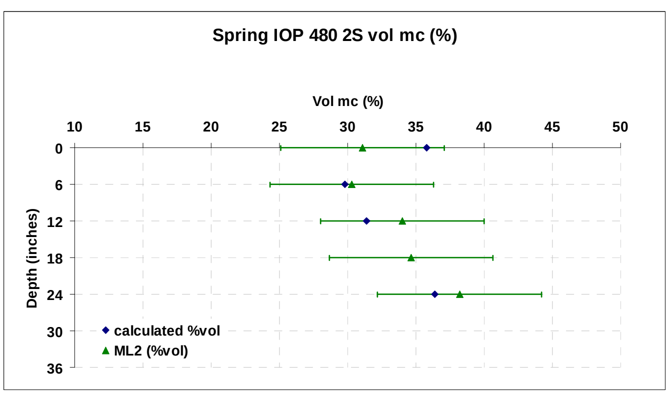
4-33 b.



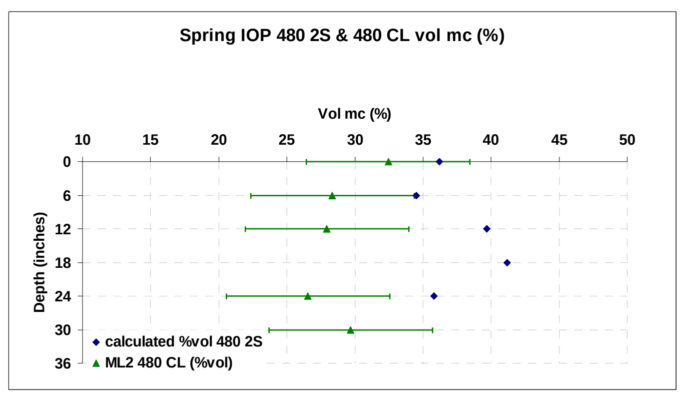
4-33 c.



4-33 d.



4-33 e.



4-33 f.

Figure 4-33. Comparison of volumetric moisture content measurements from Dynamax ML2 and converted gravimetric soil samples (spring and fall IOPs).

During fall IOP3, all of the ML2 data points fall below the calculated volumetric moisture content; at Stations 120 and 480 they are well below. Only a limited number of readings are within the ±6% error range. The ML2 moisture readings at Station 300 Centerline compare well with the calculated volumetric moisture content. This suggests two things: first, the variation in soil moisture is highly variable over a short distance; second, the amount of disturbance to the soil using an auger causes a greater measurement error because the presence of air voids will affect the readings. This is likely due to the configuration of the tip of the auger bit. The bottom of the auger hole was not flat, but had a beveled edge. Loose, difficult-to-remove soil would collect at the bottom of the hole, possibly interfering with the reading. Also the soil at the bottom of the hole was disturbed from the drilling and potentially contains more air, even after inserting the probe into the soil. This was different than excavating soil pits where the ML2 probe was inserted into relatively undisturbed soil for moisture readings. The need for accurate soil moisture readings is very important, particularly for prediction of soil strength.

Soil strength

Based on the DCP output, the soil strength was determined for layers in increments of both 6- and 12-in. thicknesses. Upon closer review of the DCP data it became clear that because the soil type at the RAS is known to be a lean clay (CL), and the penetration-per-blow readings were roughly 20 or higher, the relationship for CL soils should be used to determine the CBR. Of all the instruments used to take field measurements, the DCP is the most widely used and has a well-established, documented procedure. As shown in Figure 3-8, there is a difference in the CBR correlation for CL soils, versus the correlation for “All soils” when the penetration per blow is about 20 and above. Using this relationship produces a 40% reduction in the CBR value for a given layer, as opposed to using the relationship for “All soils.”

It is a fundamental idea that the weaker the soil strength, the fewer the number of allowable aircraft passes, and/or the lower the aircraft gross weight that the landing zone is capable of supporting. Because of this, the CBR becomes a very important value, and the best estimate is required. The “CL soil” relationship was used to estimate the CBR values for all of the readings collected during the spring, fall, and winter IOPs. For the summer IOP, the “All soils” relationship was used to estimate the soil CBR as the penetration-per-blow values fell outside of the applicable range for

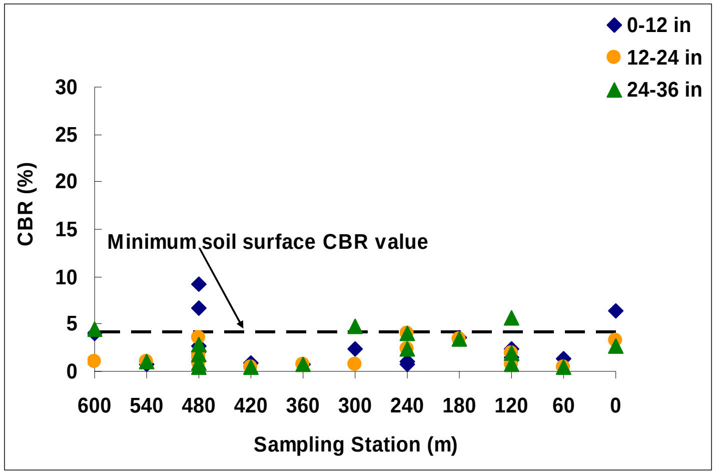
the “CL soil” relationship. The results for each season are plotted in Figure 4-34. The dashed line on each plot represents the minimum soil surface CBR value needed to support a minimum of 10 passes of a C-130 at 130-kip gross weight (Fig. 3-10). Both the spring and winter IOPs clearly show that the average CBR soil strength values with depth do not meet the minimum required strength (Fig. 4-34, a and d). Although the soil CBR values during the fall IOP show some increased strength, sampling Stations 120—360 m show a large weak area that controls the overall strength of the RAS. For the summer IOP, the CBR values for the soil surface at all sampling stations well exceed the minimum strength requirement, with the exception of sampling Station 120 m Centerline, which was 3 CBR. The CBR values with depth were also weak.

Figure 4-35 shows the estimated CBR values for each IOP based on the data for the cone penetrometer and lightweight Clegg hammer for the upper soil layer. These plots compare the estimated CBR value for the 1- to 6-in. and 6- to 12-in. layers with calculated CBR values from the DCP. Because the DCP readings tend to be unreliable in the upper layer, a minimum of 76 mm (3 in.) of penetration is recommended in a CL soil (Air Force 2002). For this reason any readings that occurred in the uppermost 76 mm (3 in.) of the layer were not included in the calculation.

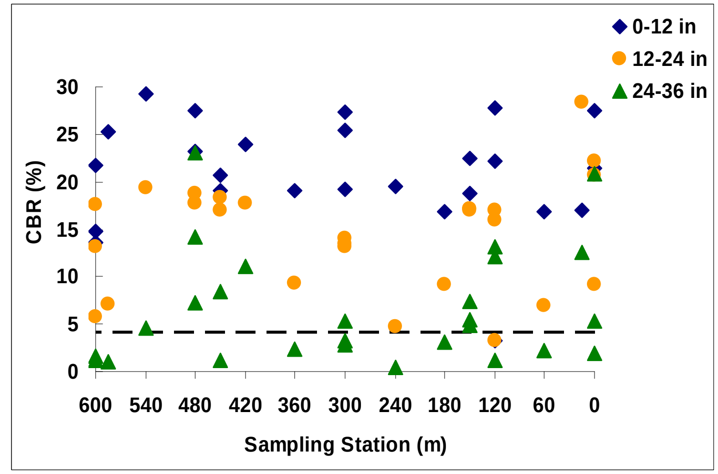
For the spring IOP2 (Fig. 4-35a), the estimated CBR for the cone penetrometer at both depths was higher than the values calculated for the DCP. The CBR for the 1- to 6-in. layer is approximately 4.5, whereas the CBR for the 6- to 12-in. layer is about 6. The CBR values from the DCP are lower, ranging in the midportion of the RAS from 2.5 to less than 1, and higher values at the end points of the North Vernon Airport RAS.

The summer IOP2 compares the CBR estimated from the lightweight Clegg hammer data with the DCP. Here, the Clegg data show high variability along the RAS with lower values toward the east end of the RAS. The lowest value, 1.4, occurs at sampling Station 120 m. This is likely due to the uneven surface when taking Clegg hammer measurements. The CBR from the DCP shows some variability, as well, with the lowest reading occurring at sampling Station 480 m with a CBR of 5.

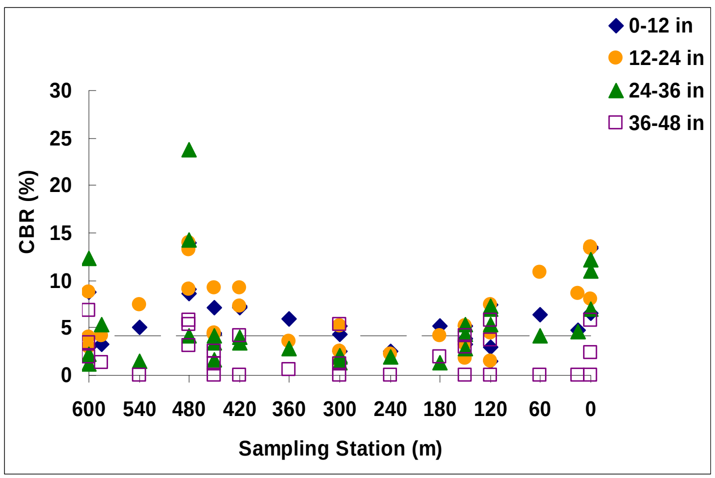
The fall and winter IOPs compare the estimated CBR for all three testing devices. For the fall, the cone penetrometer readings are slightly below the



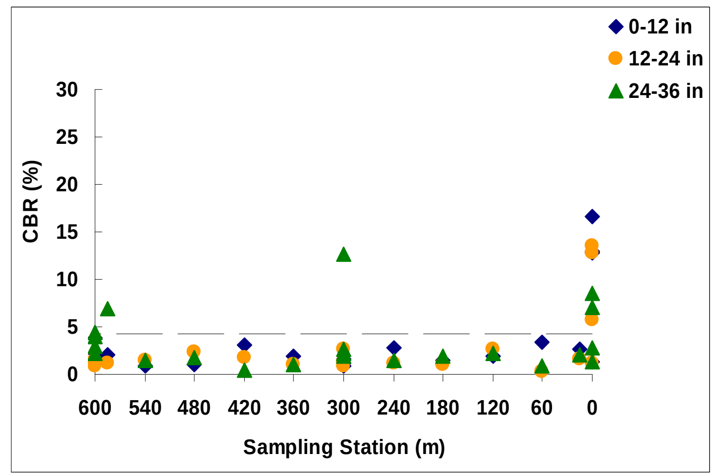
4-34 a. Spring IOP.



4-34 b. Summer IOP.

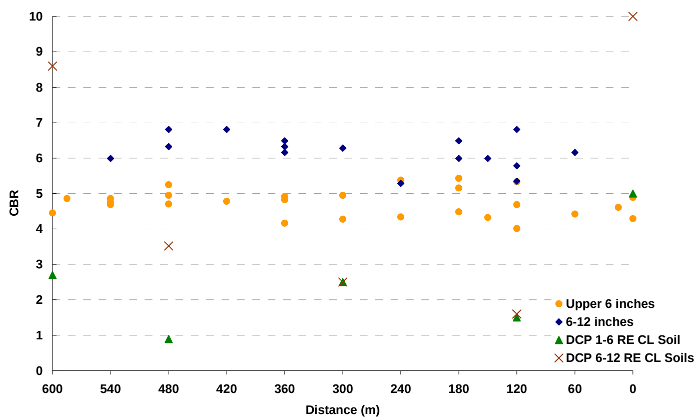


4-34 c. Fall IOP.

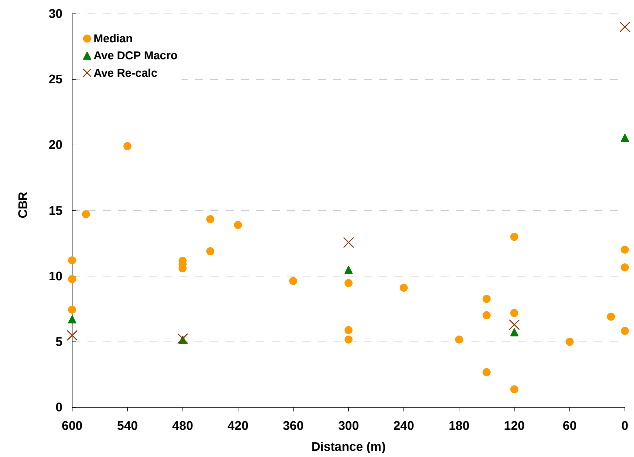


4-34 d. Winter IOP.

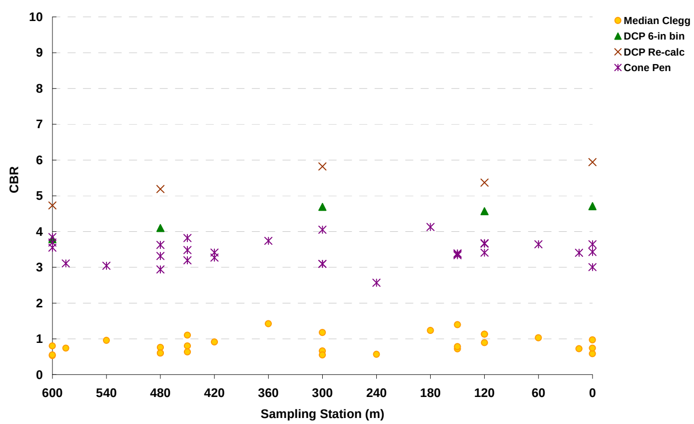
Figure 4-34. Comparison of DCP data for all IOPs.



4-35 a. Spring (cone pen)



4-35 b. Summer (Clegg hammer)



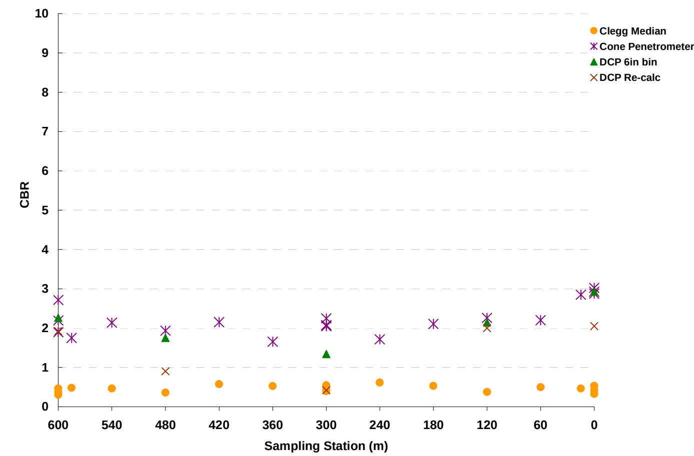


Figure 4-35. Comparison of upper soil strength for each IOP.

DCP, whereas the CBR values for the Clegg hammer consistently range below a CBR of 2 all along the RAS. The same occurs during the winter IOP4, where the cone penetrometer and the DCP correlate well around CBR of 2, whereas the CBR values from the Clegg hammer are much lower and range below 1 CBR along the RAS. A possible explanation for this is that the condition of the surface during both the fall and winter IOPs had little bare soil exposed, and perhaps that affected the readings.

Seasonal organic content

The average organic content by weight for all of the surface samples at the North Vernon Airport RAS was 0.96% (Fig. 4-36). The variability between repeat samples was as much as 27% and 30% for Stations 120 m 2 m North and 300 m Centerline, respectively. The variability between the stations and the average ranged from 25% to 69%, with the organic content of 0.3% for the first sample tested at 300 m Centerline being the lowest of all of the samples tested. This variation may be due to the tillage practices applied, the drainage patterns, and the effect of slope (M. Reynolds, personal communication, January 11, 2007).

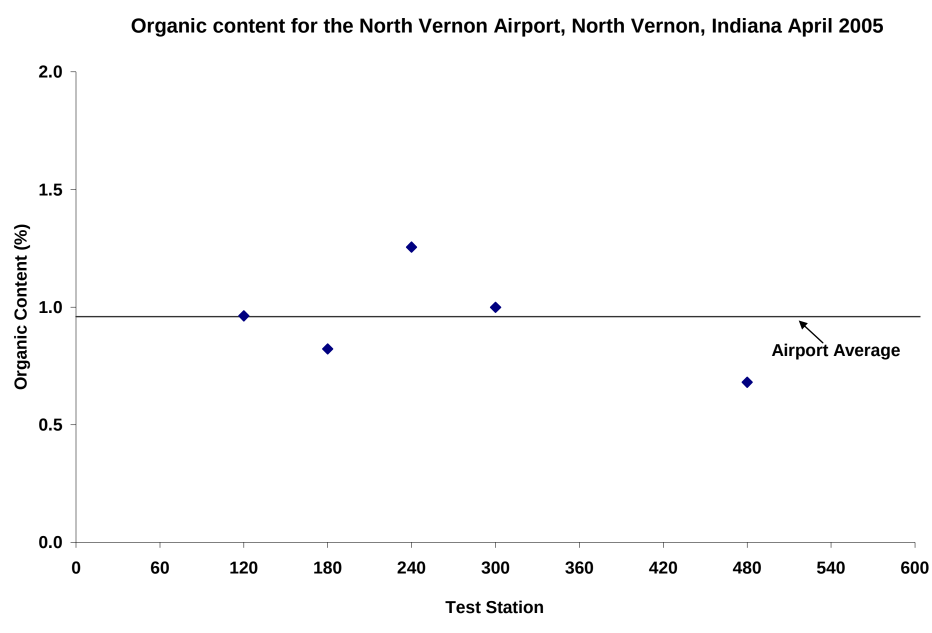


Figure 4-36. Organic content shown at OLS testing stations as compared to the average value of all organic surface samples.

4.5 Analysis

The North Vernon Airport RAS was one of many OLSs identified by the Boeing software. It was evaluated during four field visits to capture the conditions during each season. The RAS was surveyed, soil samples collected for analysis, and field measurements were taken to characterize the soil density, moisture, and strength.

The nonseasonal features of the RAS reveal that the soils present on the RAS are fine-grained, poorly draining soils; they are frost susceptible with a high percentage—75% or more—material passing the #200 sieve. Laboratory analysis characterized the soil type as predominately a silty clay with sand (CL-ML) in the upper 300 mm (12 in.) overlying a lean clay (CL) material. The calculated soil dry density values are consistent along the length of the RAS. The dry density of the upper 300-mm layer is less dense (median value of 1,473 kg/m^3 [92 lbs/ft^3]). There is a slight increase in dry density in the intermediate layer to 1,537 kg/m^3 (96 lbs/ft^3) at a depth of 300–610 mm below the surface. The dry density of the lower layer decreases to 1,457 kg/m^3 (91 lbs/ft^3).

The impacts of seasonal changes are readily seen in the surface condition survey, and in soil moisture and soil strength testing. The initial condition survey from the spring IOP identified weaker locations on the RAS from ponded surface water, the wide, shallow drainage channels that cut across the RAS, and the presence of holes in the surface from snakes, etc. Dense vegetation covered the RAS during both the summer and fall IOPs. Based on the visual survey, the presence of these features indicate weakened areas that are likely not capable of supporting aircraft operations.

The soil strength is critical in determining both the number of passes of an aircraft and the allowable gross load, using the criteria established by the Army and Air Force (1994). The minimum soil surface strength needed to support a C-130 aircraft at a gross weight of 130 kips is 4.2 CBR (Fig. 3-10). As shown in Figure 4-34, a–d, the soil strengths are insufficient to support aircraft operations.

5 Ford Farm RAS

5.1 Site description

Ford Farm RAS is located southeast of Dupont, IN, approximately 30 minutes south of North Vernon off of Highway 7 in Jefferson County. Ford Farm RAS is oriented in a northeast-southwest direction and, similar to the North Vernon Airport RAS, located on a privately owned, actively farmed field. The aerial view in Figure 5-1 (image date unknown) superimposes an outline of the RAS on the field. This illustration shows the approximate location of the RAS in the field, along with some of the natural features of both the field and the surrounding area. Ford Farm RAS is 600-m (1,968-ft) long and 20-m (65-ft) wide. The OLS start point is located at northing 4303798 m, easting 629760 m, and the end point is at northing 4303291 m, easting 629460 m, based on WGS84 UTM Zone S16.

To the north-northwest of the RAS is a stand of deciduous trees. A grade with an active railroad, at times obscured by the stands of trees, is located northeast of the RAS with a northwest-southeast orientation. Another stand of deciduous trees borders the RAS to the south. On the west side, at about the RAS midpoint, is a drainage channel that flows from the RAS toward the trees further to the west. As indicated in Figure 5-1, this feature crossed the RAS in two places that are seasonally wet and rutted from farm equipment. Similar conditions were observed in the northeastern area indicated on the aerial image. Figure 5-1 also shows where the weather station was located in relation to the RAS. It was placed on the eastern edge of the field in a grassy, sloped area. This location was out in the open, where the stands of trees did not interfere with the readings, and it was on the same elevation as the RAS. This location also protected the instruments, particularly the subsurface instrumentation, and data collection equipment from the activities in the field. Figure 5-2, taken during summer IOP2, shows a closer aerial view of the OLS and the vegetation coverage.

Of the two parallel OLSs identified by the Boeing software this RAS was selected for field evaluation after the initial site visit of the area in April 2005. Each seasonal IOP visit was at the same time as those for the North Vernon RAS; these dates are listed in Table 3-1.

5.2 Evaluate RAS

Field activities during IOP1 included surveying the site to lay out the RAS sampling grid (Fig. 3-4.) A complete summary of all measurements recorded during each IOP and at each sampling station is given in Table C-1, Appendix C.

Based on the site survey, the Ford Farm RAS slopes over the length downward 0.4%, representing an elevation change of 2.06 m, from northeast to southwest. The vertical datum was set using Delorme Topo USA digital map software (Version 4.0) to determine the elevation of the sampling stations. Figure 5-3 illustrates the slope. During IOP3, the surface relief was refined using the tripod-mounted laser level. The measurements were made at 5-m increments along the centerline of the RAS. A spacing of 1 m was used in areas of more subtle surface variation, such as the lower lying drainage ditch. These data were then compared with the total station survey data collected from IOP1 (Fig. 5-3). The surface profile data collected with the laser level closely track the survey data and clearly show the ruts in the drainage areas located at 84 m and 200 m Centerline.

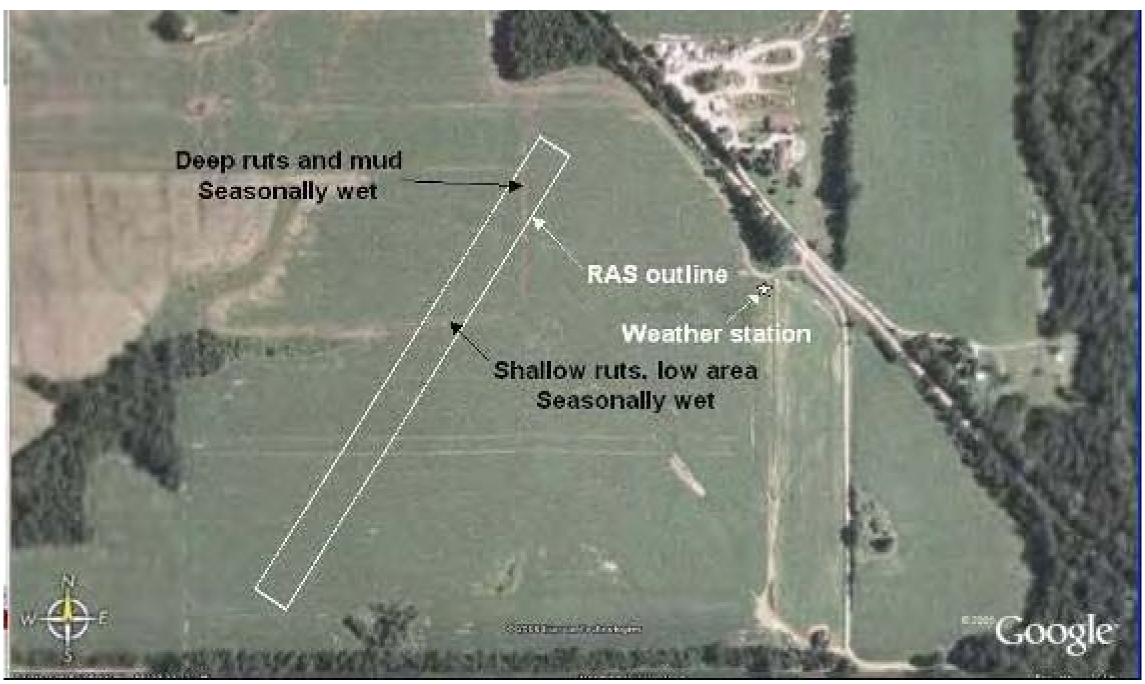


Figure 5-1. Aerial view of the Ford Farm RAS location (outline of RAS is indicated).

Figure 5-2. Aerial view of the Ford Farm RAS, summer IOP2

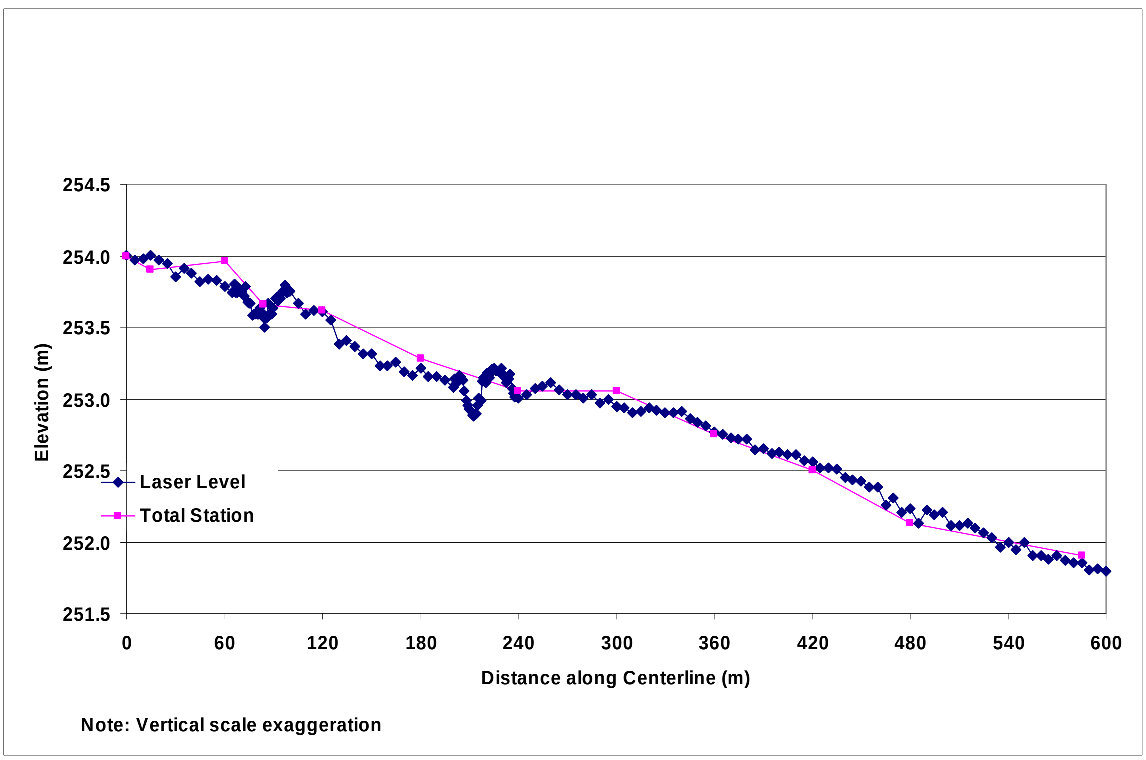


Figure 5-3. Elevation change over length of Ford Farm RAS.

5.3 Field testing

5.3.1 Nonseasonal conditions

This section describes the soil field measurements collected at the Ford Farm RAS that are anticipated to be unaffected by seasonal change: soil texture, soil color identification, and soil density. Photographs of the in situ surface condition at each soil pit location are shown in Figure 5-4, a—f.

Soil characteristics

In general, the soil in the upper 300 mm (12 in.) consists of a silty clay with sand (CL-ML) overlying a lean clay (CL) below 305 mm. The range of values for the plasticity index in the upper 300 mm is from 6 to 12, and there is a high percentage, greater than 70%, of material finer than 0.074 mm (#200 sieve). Table 5-1 summarizes the data from the soil samples analyzed from the RAS. Grain size distributions of the surface soils are given in Figure 5-5. Grain size distributions for the other soils sampled at the Ford Farm RAS are given in Figures C-1 to C-5 in Appendix C.

Plotting the Atterburg limits (liquid limit and plasticity index) on a plasticity chart (Fig. 5-6) shows the classification of these samples. Soil samples from Centerline sampling Stations 180, 300, 420, and 480 m were collected from the auger cuttings during IOP2.

Photographs in Figures 5-7 and 5-8 show examples of the material in the upper 600 mm at the soil pit located at 300 m Centerline and 480 m 2 m East and are representative of the upper layer along the RAS. There is a distinct change in the soil color, most likely associated from the activities from farming (Fig. 5-7). Free water is also visible in the bottom of the pit.

5-4a. 84 m Centerline “wet” (west).

5-4b. 120 m 2 m West.

5-4c. 180 m 2 m East.

5-4d. 300 m Centerline.

5-4e. 420 2 m West.

5-4f. 480 m 2 m East.

Figure 5-4. In situ surface conditions at Ford Farm RAS soil pit locations.

Table 5-1. Soil field measurements taken at the Ford Farm RAS sampling points during each IOP.

	Sampling Station																							
Soil properties	84m Centerline East (Dry)	120m 2m West	300m Centerline	84m Centerline East (Dry)	84m Centerline West (Wet)	120m 2m West	300m Centerline	480m 2m East	84m Centerline East (Dry)	84m Centerline West (Wet)	120m 2m West	300m Centerline	480m 2m East	120m 2m West	300m Centerline	480m 2m East	180m Centerline	300m Centerline	420m Centerline	480m Centerline	180m Centerline[A]	300m Centerline[B]	420m Centerline[C]	480m Centerline[D]
Depth below surface	**Surface**			**25 - 152 mm (1 - 6 inches)**					**305 mm (12 inches)**					**610 mm (24 inches)**			**305 - 660 mm (12 - 26 inches)**				**610 - 838 mm (24 - 33 inches)**			
Season Sample Collected	Spring			Spring					Spring					Spring			Summer				Summer			
USCS Soil Description	CL/ML-CL Lean clay w/sand		CL-ML/CL Silty clay w/sand	CL-ML Silty clay w/sand					CL Lean clay w/sand		CL-ML Silty clay w/sand	CL Lean clay w/sand		CL Lean clay w/sand			CL Lean clay w/sand				CL Lean clay w/sand			
Liquid Limit	30.6	27.9	24.8	25	25	25	24	25	25	25	24	27	24	26	31	29	27	27	28	27	27	30	29	29
Plasticity Index	11.5	7.4	6.4	7	7	5	7	6	8	8	6	10	9	9	11	11	9	10	11	9	9	12	10	12
% Fines	75.3	74.3	71.3	74.3	73.8	72.5	72.0	72.8	80.2	79.6	77.1	78.2	77.4	81.5	78.8	78.3	77.1	78.2	76.7	77.5	77.1	77.8	76.9	79.2
Specific Gravity	No data	No data	No data	2.62	2.59	2.59	2.60	2.64	2.63	2.61	2.66	2.67	2.61	2.58	2.64	2.60	2.66	2.67	2.66	2.66	2.67	2.62	2.69	2.68

Notes:
[A] Sample depth was 24-33 inches below the surface.
[B] Sample depth was 24-31 inches below the surface.
[C] Sample depth was 24-29 inches below the surface.
[D] Sample depth was 24-31 inches below the surface.

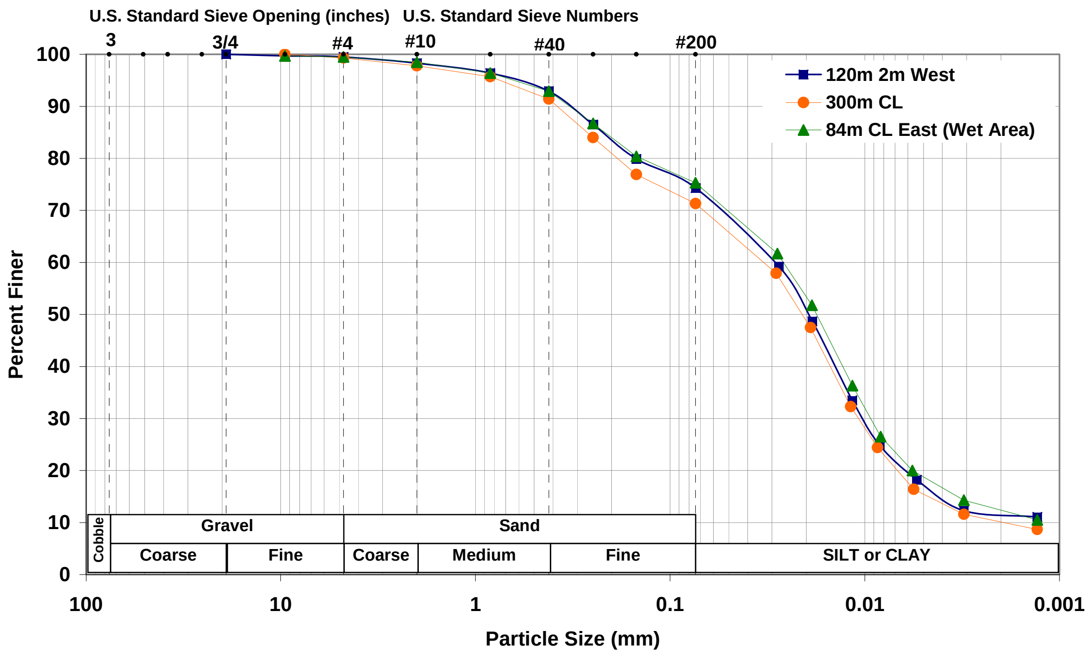


Figure 5-5. Comparison plot. Summary of soil classification for 0.6-m (2-ft) soil pits surface samples, Ford Farm RAS.

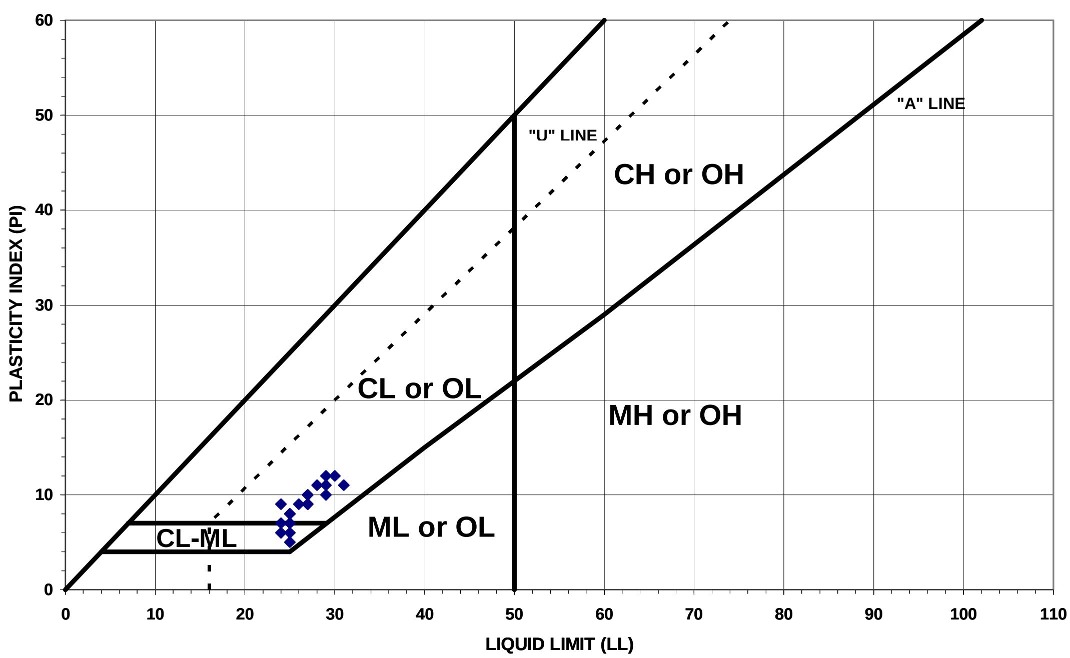


Figure 5-6. Plasticity chart for soil samples from Ford Farm RAS.

Figure 5-7. Soil pit at Station 300 m Centerline, upper 600 mm of soil pit.

Figure 5-8. Soil pit at Station 480 m 2 m East, upper 600 mm of soil pit.

Soil color

Table 5-2 summarizes the surface color at the specific sampling stations.

Soil density

Concurrent with digging soil pits, soil density was measured with the Troxler nuclear density gauge. The procedure for taking density readings was described earlier in Section 3. Table 5-3 lists the dry density values calculated using the wet density measurements from the Troxler and the gravimetric moisture contents from the soil samples collected as the soil pits were excavated. The dry density values from the soil pits are plotted in Figure 5-9 and show a range of values, from 90 lbs/ft^3 (14,416 kg/m^3) to 98 lbs/ft^3 (15,698 kg/m^3).

5.3.2 Seasonal conditions

Four field visits, one during each season, were made to the Ford Farm RAS to observe changes to the field conditions. The general field conditions for each IOP are shown in Figure 5-10, a—d. During spring IOP1, half of the field had been tilled and planted with corn. The surface of the RAS was littered with vegetation debris from the previous planting season (Fig. 5-10a). Once the field conditions were favorable for planting, a corn crop was planted in the field. Field testing during IOP2 (summer, Fig. 5-10b) saw dense vegetation with corn planted in tight rows and roughly 8-ft high. There were also large, dense patches of weeds in the field. The drainage areas were characteristically open, wet areas with some mud and shorter grasses. The field had been harvested before IOP3 and the surface was scattered with a shallow layer of vegetative debris. (Fig. 5-10c). The photograph in Figure 5-10c was taken at the RAS start point (Station 0 m Centerline). The low-lying drainage area is visible as a dark patch on the right side of the photograph about midway, sloping slightly from left to right (east to west). During IOP4, the surface of the RAS remained covered with vegetative debris (Fig. 5-10d). There were cracks in the soil surface (Fig. 5-10e). The presence of these discontinuities made surface strength measurements difficult.

During each IOP, observations on the surface condition and measurements on the soil moisture and soil strength were collected. Surface soil samples collected during the different IOPs were analyzed to determine any seasonal variability in the organic content.

Surface condition

The series of photographs in Figure 5-11 illustrate the condition of the surface during the spring IOP1. In the vicinity of 84 m Centerline sampling station (Fig. 5-11a), there was a drainage area that was muddy with deep ruts. Shown in Figure 5-11b is another seasonally wet area between sampling Stations 180 m and 240 m Centerline with shallow ruts. The remaining sections of the RAS are flat with few notable characteristics (Fig. 5-11, c—e). Because the field work during the spring IOP began after the field had been tilled and prepared for the planting season, there was little vegetation growing on the surface. Figure 5-12 identifies *Ranunculus acris* and *Agropyron repens* as two types of vegetation on the Ford Farm RAS.

Table 5-4 notes the observations of the condition of the surface for each IOP, and Figures 5-13—5-15 show photographs of the surface condition from sampling Station 300 m Centerline looking north to sampling Station 0 m Centerline (a) and south to sampling Station 600 m Centerline (b) taken during each IOP. During both the fall and winter IOPs, the surface of RAS was covered with vegetation debris (stalks, leaves, and corn cob pieces), as well as some low-growing surface vegetation. The soil surface was dry and cracked during the winter IOP4.

Table 5-2. Summary of Munsell soil color identification at the Ford Farm RAS.

	Sampling Station													
	120 m 2 m West	0 m Center-line	15 m Center-line	60 m Center-line	120 m Cen-terline	180 m Cen-terline	240 m Cen-terline	300 m Cen-terline	360 m Cen-terline	420 m Cen-terline	480 m Cen-terline	540 m Cen-terline	585 m Cen-terline	600 m Cen-terline
Season sample collected	Spring	Winter												
Munsell color identification	10 yr 8/2 Very pale orange	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 5/4 Yellow-ish brown	10 yr 4/2 Dark grayish brown

Table 5-3. Calculated dry density values for the Ford Farm RAS.

			April						August					October					
Sampling Station	Depth (inches)	Depth (mm)	wet density (lbs/ft^3)	moisture content (w) %	dry density (lbs/ft^3)	dry density (kg/m^3)	volumetic moisture content %	ML2 volumetic moisture content (median) %	wet density (lbs/ft^3)	moisture content (w) %	dry density (lbs/ft^3)	dry density (kg/m^3)	volumetic moisture content %	wet density (lbs/ft^3)	moisture content (w) %	dry density (lbs/ft^3)	dry density (kg/m^3)	volumetic moisture content %	ML2 volumetic moisture content (median) %
120 2W	0	0												115.6	22.2	94.6	1,515.3	33.6	
	6	152.4	111.5	21.3	91.9	1,472.1	31.4	32.5						115.6	23.2	93.8	1,502.5	34.9	24.0
	12	304.8	118.5	17.1	101.2	1,621.1	27.7	34.9						122.3	23.5	99.0	1,585.8	37.3	28.1
	18	457.2																	
	24	609.6	115.5	24.7	92.6	1,483.3	36.7	38.9											
	30	762																	
300 CL	0	0												110.5	25.8	87.9	1,408.0	36.3	
	6	152.4	113.3	18.8	95.4	1,528.2	28.7	31.4						110.5	21.8	90.7	1,452.9	31.7	27.4
	12	304.8	119.6	20.3	99.4	1,592.2	32.3	37.6	119.6	21.8	98.2	1,573.0	34.3	119.5	25.6	95.2	1,525.0	39.0	33.1
	18	457.2												115.4	21.9	94.7	1,516.9	33.2	
	24	609.6	114.9	20.3	95.5	1,529.8	31.1	39.6	114.9	22.0	94.2	1,508.9	33.2	116.4	23.9	93.9	1,504.1	36.0	32.1
	30	762																	
480 2E	0	0																	
	6	152.4	112.8	18.1	95.5	1,529.8	27.7	31.2						101.1	21.8	83.0	1,329.5	29.0	29.7
	12	304.8	118.8	20.5	98.6	1,579.4	32.4	35.3						120.6	21.5	99.3	1,590.6	34.1	31.0
	18	457.2																	
	24	609.6	112.3	26.6	88.7	1,420.8	37.8	39.4											
	30	762																	

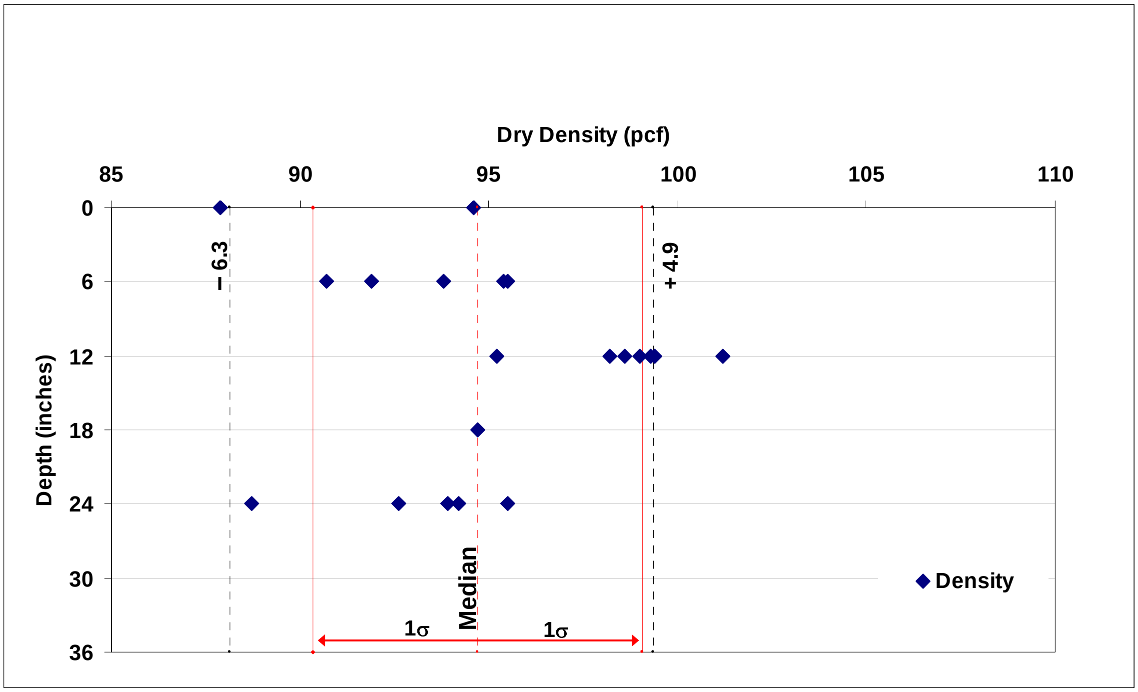


Figure 5-9. Calculated dry density values at Ford Farm RAS.

5-10a. Spring.

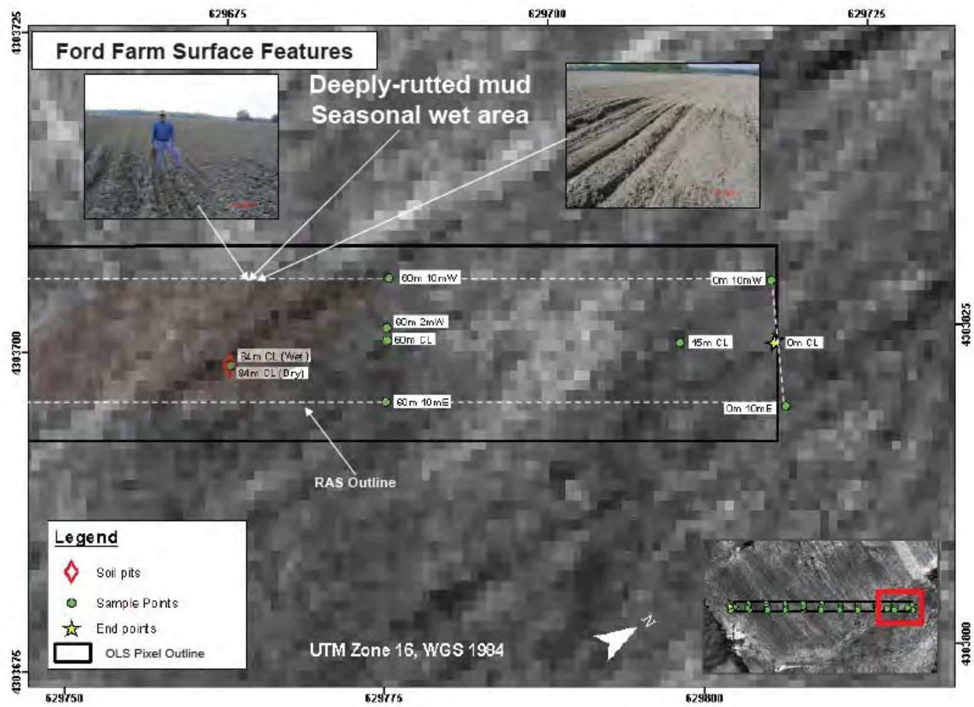
5-10b. Summer.

5-10c. Fall.

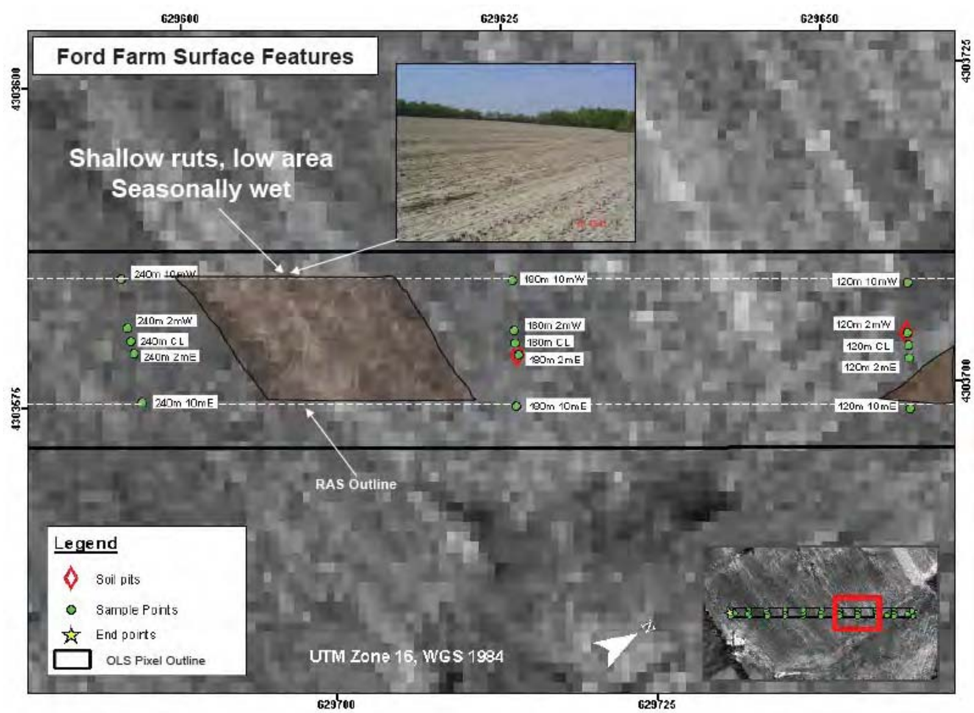
5-10d. Winter.

5-10e. Winter.

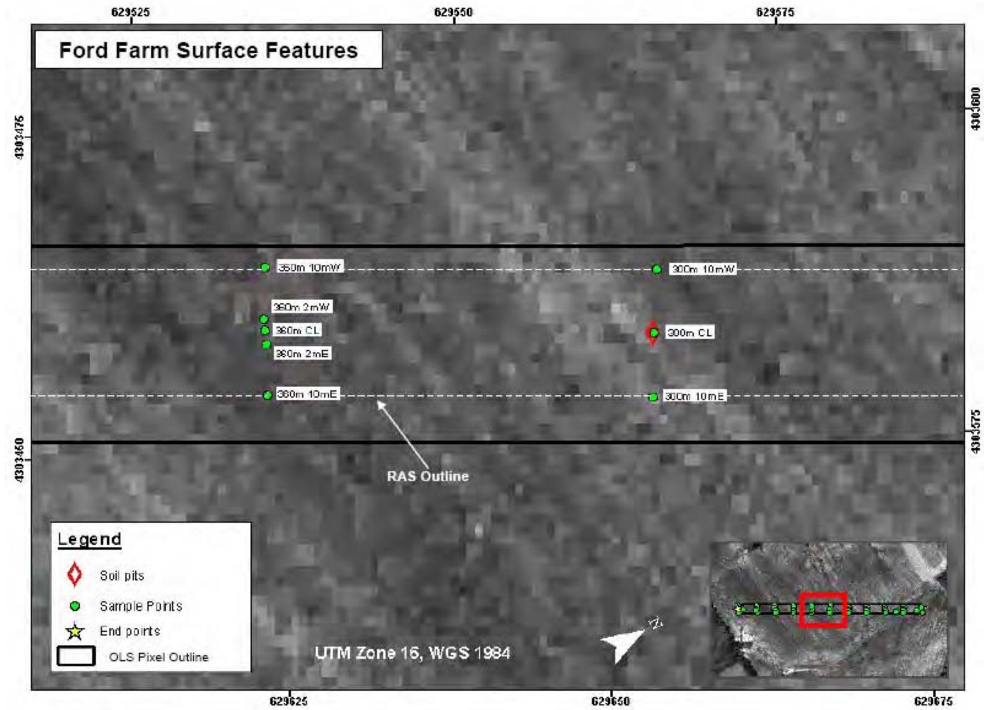
Figure 5-10. Site conditions of Ford Farm RAS during each IOP: (a) spring IOP1, view looking southwest down centerline from Station 300 m Centerline; (b) summer IOP2, view of weather station showing density of corn field on the left (RAS not pictured); (c) fall IOP3, view down RAS centerline looking southwest from Station 0 m Centerline; (d) winter IOP4, view down RAS centerline looking northeast from Station 600 m Centerline; (e) winter IOP4, cracked soil surface at Station 300 m Centerline.


Ford Farm Surface Features
Deeply-rutted mud
Seasonal wet area
RAS Outline
Legend
Soil pits
Sample Points
End points
OLS Pixel Outline
UTM Zone 16, WGS 1984

5-11a.

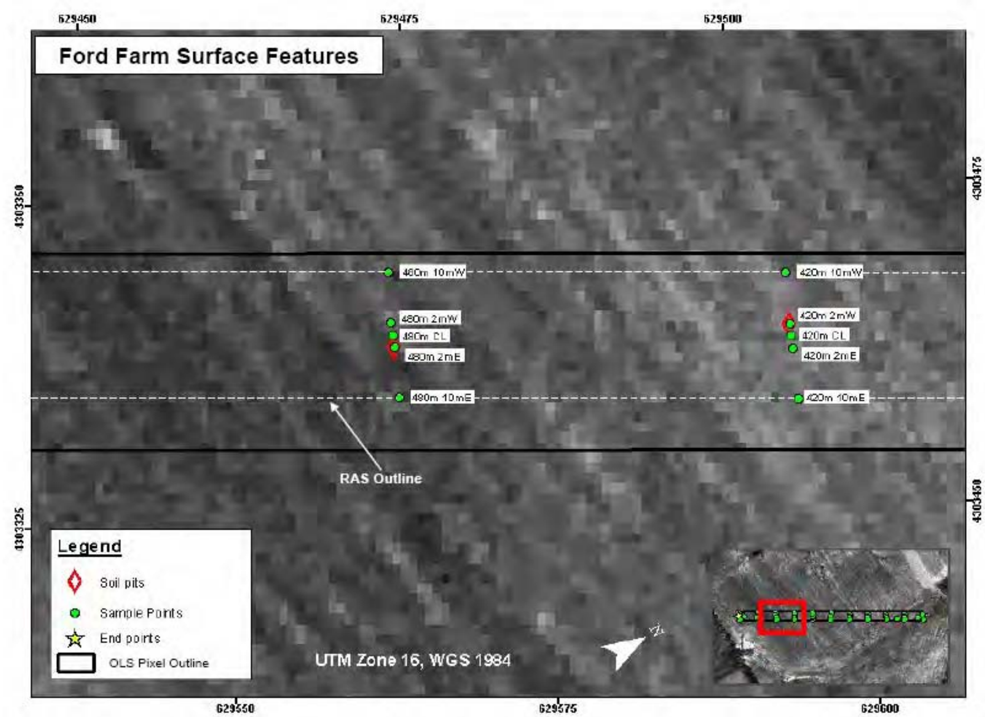

Ford Farm Surface Features
Shallow ruts, low area
Seasonally wet
RAS Outline
Legend
Soil pits
Sample Points
End points
OLS Pixel Outline
UTM Zone 16, WGS 1984

5-11b.



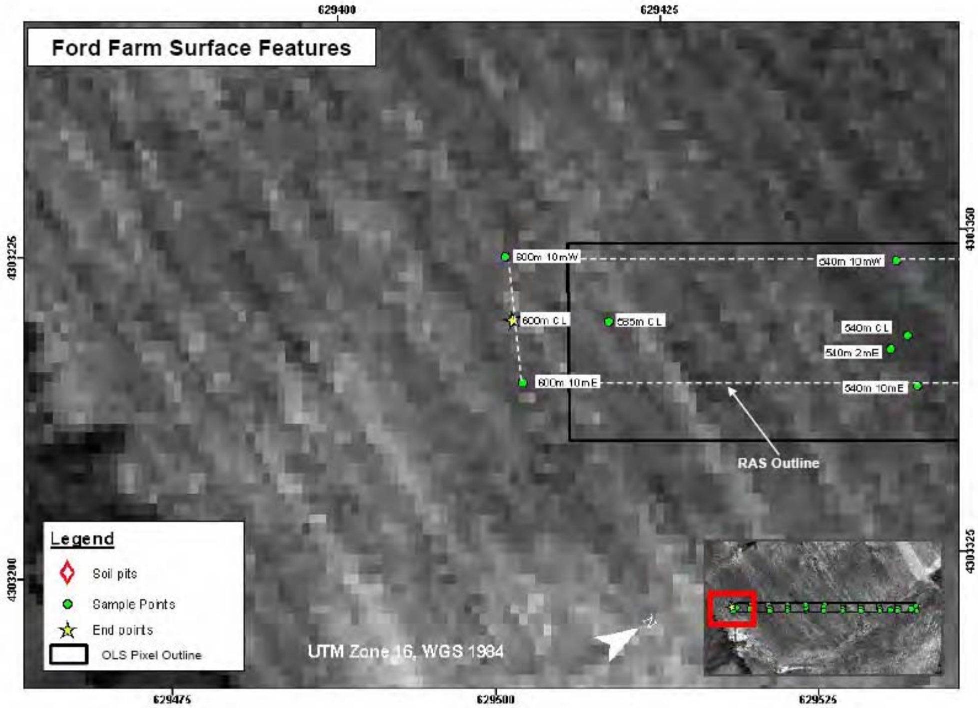
Ford Farm Surface Features
629525
629550
629575
360m 10mW
300m 10mW
360m 2mW
360m CL
360m 2mE
300m CL
360m 10mE
300m 10mE
RAS Outline
Legend
Soil pits
Sample Points
End points
OLS Pixel Outline
UTM Zone 16, WGS 1984
629625
629650
629675

5-11c.



Ford Farm Surface Features
629450
629475
629500
480m 10mW
420m 10mW
480m 2mW
480m CL
480m 2mE
420m 2mW
420m CL
420m 2mE
480m 10mE
420m 10mE
RAS Outline
Legend
Soil pits
Sample Points
End points
OLS Pixel Outline
UTM Zone 16, WGS 1984
629550
629575
629600

5-11d.



5-11e.

Figure 5-11. Surface condition of Ford Farm RAS from spring IOP1.

Figure 5-12. *Ranunculus acris* and *Agropyron repens*.

Table 5-4. Surface feature observations from spring and summer IOPs.

	Spring		
	Distress Types	Condition	Comments
1.	Potholes or depressions	Exceed 6-in. deep	Surface drainage ditches
2.	Ruts	Exceed 6-in. deep	Deep ruts from farm equipment at 84 m Center-line
3.	Corrugations	Not applicable	
4.	Rolling resistance material	Low severity	None observed
5.	Loose aggregate	Not applicable	
6.	Dust	Low severity	
7.	Layer failure	Not applicable	
8.	Vegetation	Low severity	
9.	Standing water / wet areas	Present	Low, muddy drainage area near 84 m Centerline
10.	Rock outcropping	Not applicable	
11.	Snow	Not applicable	
12.	Other	Not applicable	
	Summer		
	Distress Types	Condition	Comments
1.	Potholes or depressions	Exceed 6-in. deep	Surface drainage ditches
2.	Ruts	Exceed 6-in. deep	Rutted area at 84 m Centerline
3.	Corrugations	Not applicable	
4.	Rolling resistance material	Not applicable	None observed
5.	Loose aggregate	Not applicable	
6.	Dust	Not applicable	
7.	Layer failure	Not applicable	
8.	Vegetation	High dense corn	Corn growing in field and dense patches of weeds
9.	Standing water / wet areas	Exceed 6-in. deep	Low, muddy drainage area near 84 m Centerline
10.	Rock outcropping	Not applicable	
11.	Snow	Not applicable	
12.	Other	Not applicable	
	Fall		
	Distress Types	Condition	Comments
1.	Potholes or depressions	Red	Surface drainage ditches
2.	Ruts	Green	
3.	Corrugations	Not applicable	
4.	Rolling resistance material	Green	None observed
5.	Loose aggregate	Not applicable	
6.	Dust	Green	
7.	Layer failure	Not applicable	

Table 5-4 (cont'd). Surface feature observations from spring and summer IOPs.

	Fall		
	Distress Types	Condition	Comments
8.	Vegetation	Green	Field harvested and cleared
9.	Standing water / wet areas	Red	Low, muddy drainage area near 84 m Centerline
10.	Rock outcropping	Not applicable	
11.	Snow	Not applicable	
12.	Other	Not applicable	
	Winter		
	Distress Types	Condition	Comments
1.	Potholes or depressions	Red	Surface drainage ditches
2.	Ruts	Green	
3.	Corrugations	Not applicable	
4.	Rolling resistance material	Green	None observed
5.	Loose aggregate	Amber	Small clumps of soil on surface
6.	Dust	Green	
7.	Layer failure	Not applicable	
8.	Vegetation	Green	Field harvested and cleared
9.	Standing water / wet areas	Red	Low, muddy drainage area near 84 m Centerline
10.	Rock outcropping	Not applicable	
11.	Snow	Not applicable	
12.	Other	Not applicable	

a. b.

Figure 5-13. Spring IOP1 views down Ford Farm RAS centerline north (a) and south (b) from Station 300 m Centerline.

a. b.

Figure 5-14. Fall IOP3 views down Ford Farm RAS centerline north (a) and south (b) from Station 300 m Centerline.

a.

b.

Figure 5-15. Winter IOP4 views down Ford Farm RAS centerline north (a) and south (b) from Station 300 m Centerline.

Soil moisture

Soil moisture measurements were taken with depth using the Dynamax ML2 probe. A similar approach was used at the Ford Farm as was used at North Vernon Municipal Airport. The readings for each IOP are shown in Tables C-2—C-5 in Appendix C. During spring IOP1, measurements were taken while excavating the soil pits; a gas-powered auger was used during the remaining IOPs. A minimum of three readings were collected at each test point and used to determine the median value. During spring IOP1 the soil moisture varies on the surface from 24% to 32% (Fig. 5-16). Below the surface, the overall moisture content increases with depth and the values are more uniform. At 300 mm (12 in.) below the surface the median moisture content values show a tight range from 35% to 37%. At a depth of 600 mm (24 in.) below the surface, the readings are above 38%, close to saturation.

For summer IOP (Fig. 5-17), the median moisture content readings taken at each sampling point along the RAS are compared to the overall median value at that depth (the solid line). The overall median values for each depth show a decrease in the moisture content of 8—10%. Both the fall and winter IOPs show an increase in the overall median values at each depth. As shown in Figure 5-18 the moisture content at 300 mm (12 in.) has the highest moisture content, exceeding the values at 760 mm (30 in.) below the surface. During the winter IOP, the range of the median values at each depth are close, from 32% to 38% (Fig. 5-19).

Soil strength

Soil strength profile measurements using a DCP were taken during each IOP using a similar sampling pattern as described for North Vernon Municipal Airport. The CBR values determined for each 150-mm (6-in.) and 300-mm (12-in.) increments from each IOP are shown in Tables C-6—C-9, Appendix C. Similar to the North Vernon Airport RAS, the data were divided into three layers, the thickness of each layer being 300 mm, and the CL soil relationship used to determine the CBR value. The layer thicknesses and corresponding CBR values for each IOP are shown in Figure 5-20, a—d. The dashed line corresponds to the minimum surface soil strength value (Air Force 2002; HQ Army 1994).

The strength of the upper soil layer was measured using the DCP for each IOP, the cone penetrometer for the spring, fall, and winter IOPs, and the lightweight Clegg hammer during the summer, fall, and winter IOPs. The resulting CBR values from the upper soil strength measurements are shown in Figure 5-21, a—d.

The data plotted in Figure 5-21, a—d, are the CBR values for the upper 6 in. The cone penetrometer readings in the upper 6 in. are averaged and then a CBR value is calculated. For the lightweight Clegg hammer, the CBR value is determined from the fourth drop. The figure shows that the CBR values vary each season, with higher values during the summer and fall, and weaker values during the spring and winter. In addition, the CBR value varies along the RAS. The plots show the difference in CBR values from each instrument. The DCP tends to consistently give higher readings during each season. The CBR values from the cone penetrometer are less than those from the DCP, and the plot for the fall IOP clearly shows the differences in the readings from each instrument. The CBR values for the Clegg hammer are consistently lower, and in some cases by as much as 50%, than either the DCP or the cone penetrometer.

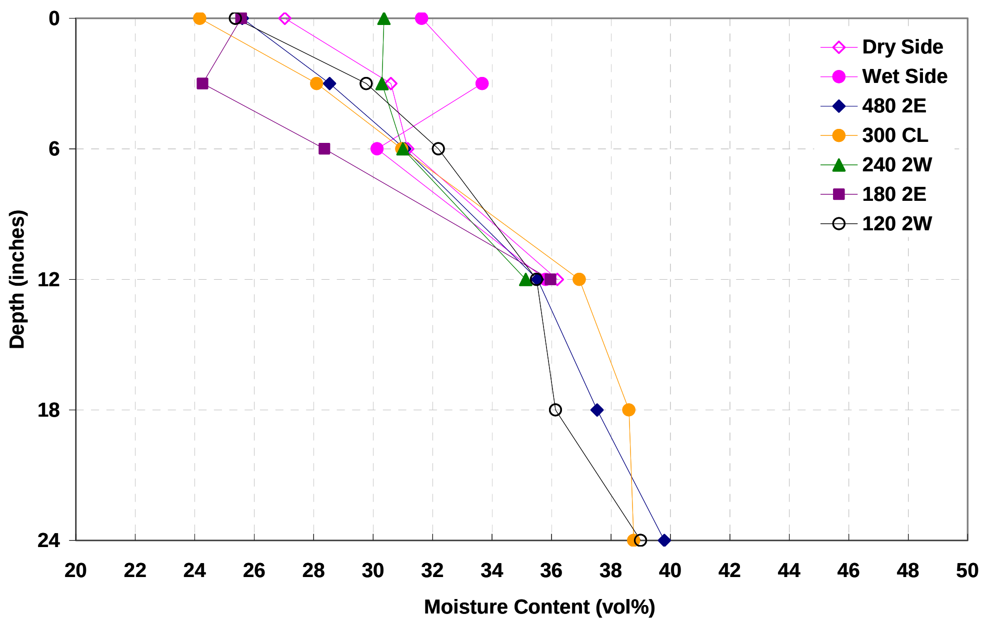


Figure 5-16. Ford Farm RAS volumetric moisture content readings with depth for all soil pit locations, spring IOP1

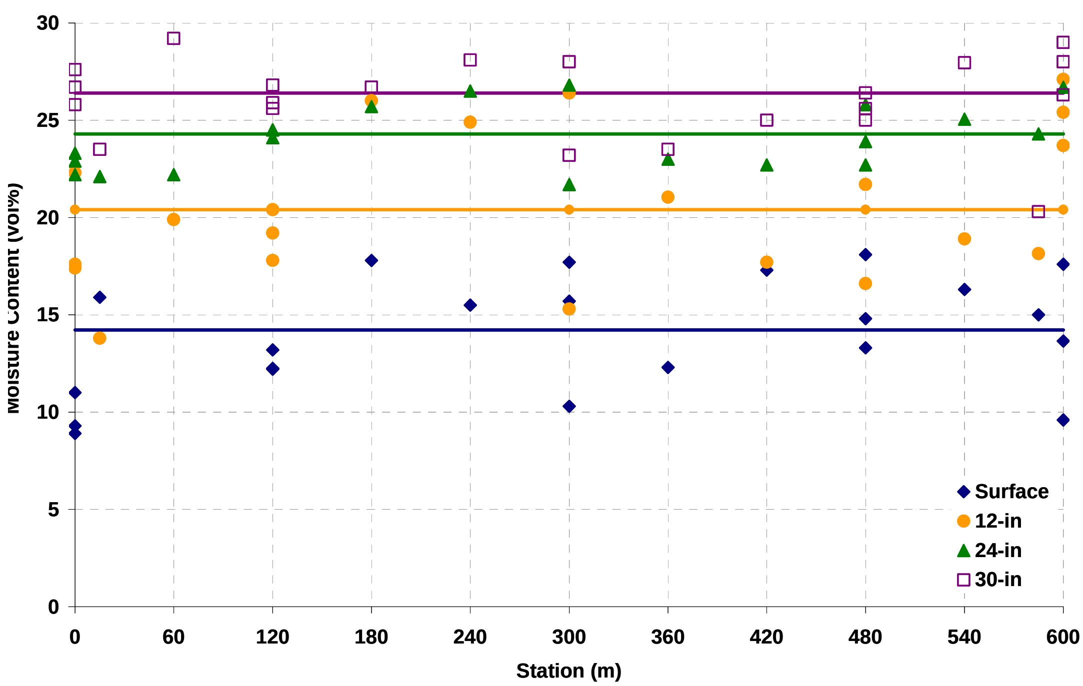


Figure 5-17. Ford Farm RAS volumetric moisture content readings with depth, summer IOP2.

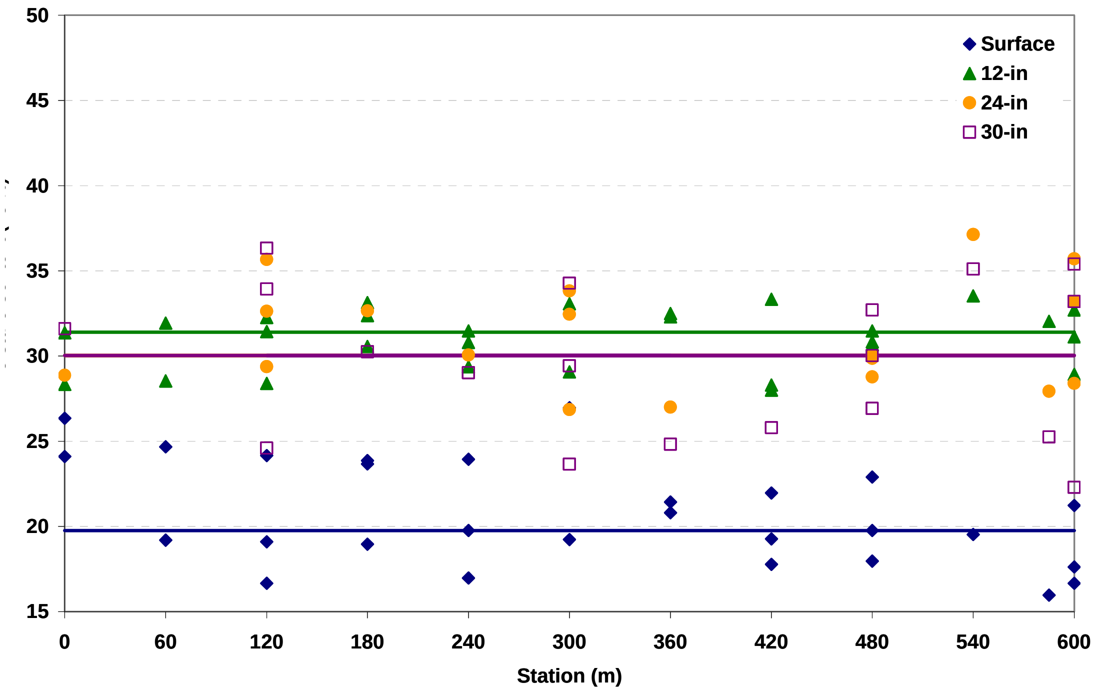


Figure 5-18. Ford Farm RAS volumetric moisture content readings with depth, fall IOP3.

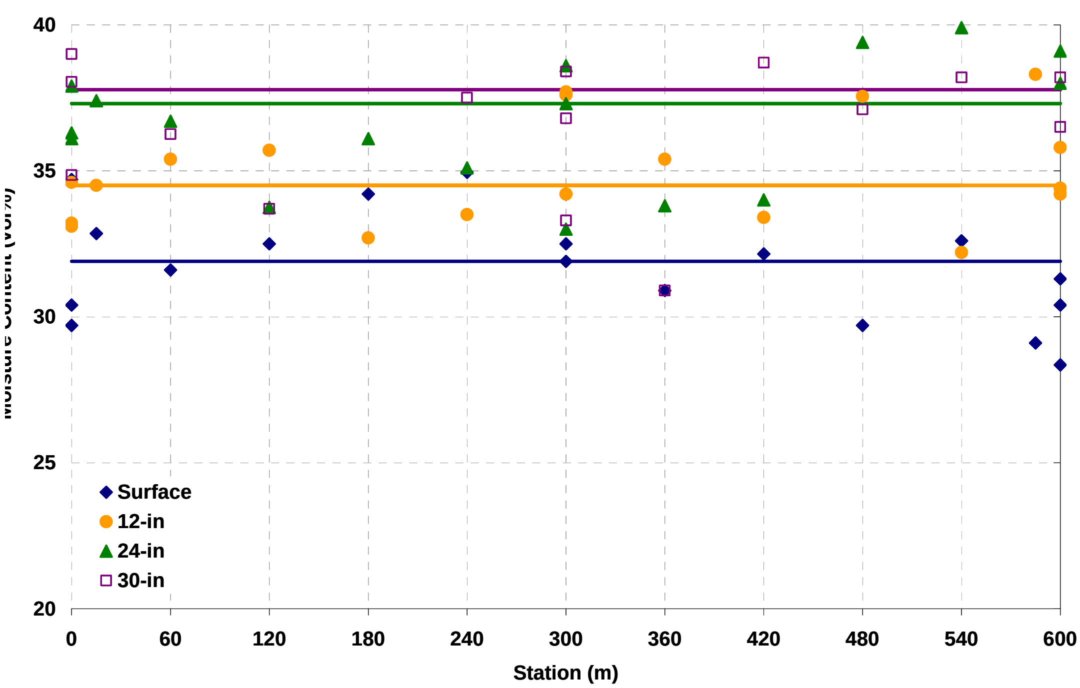
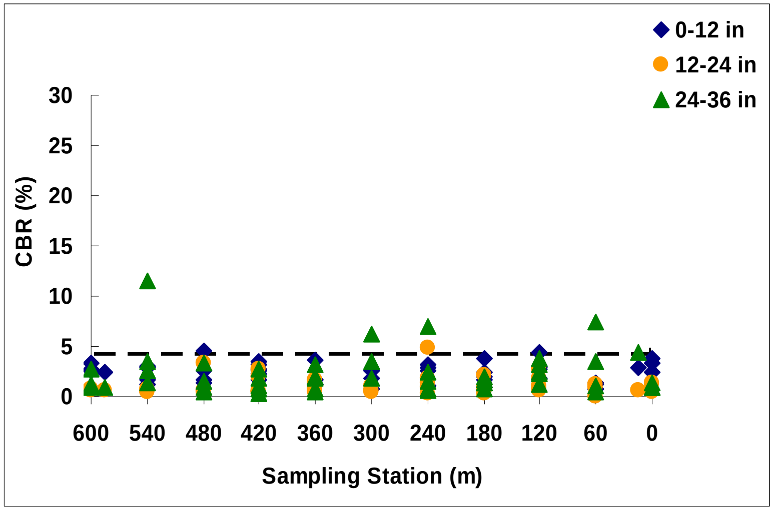
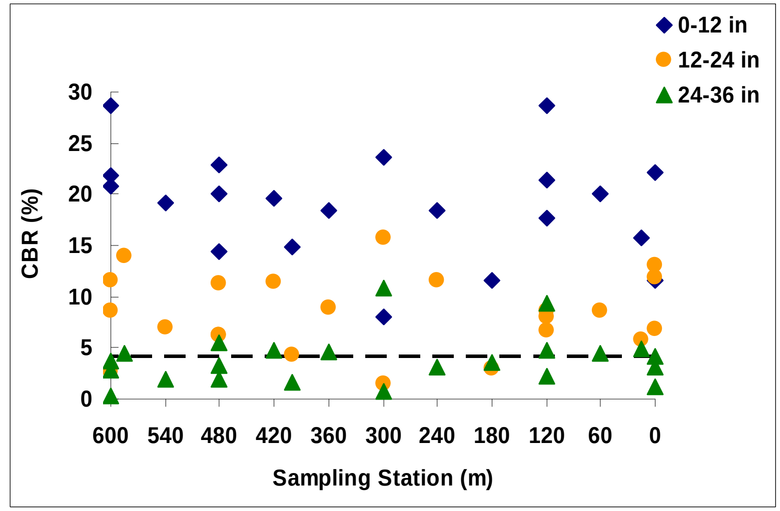


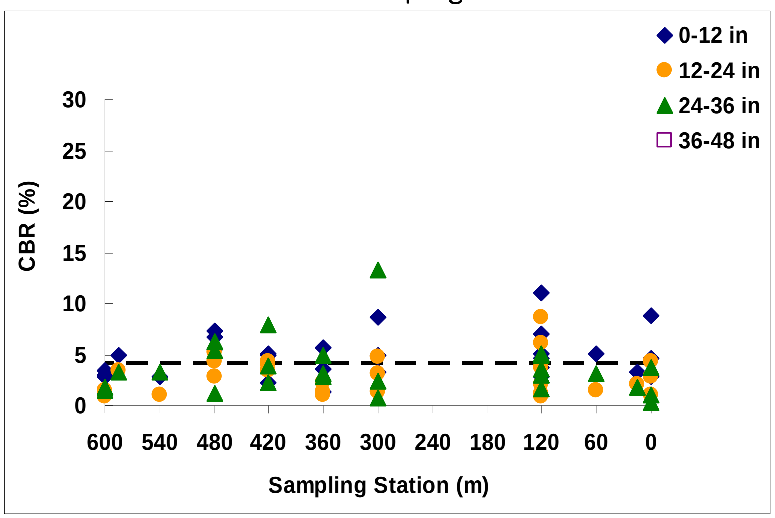
Figure 5-19. Ford Farm RAS volumetric moisture content readings with depth, winter IOP4.



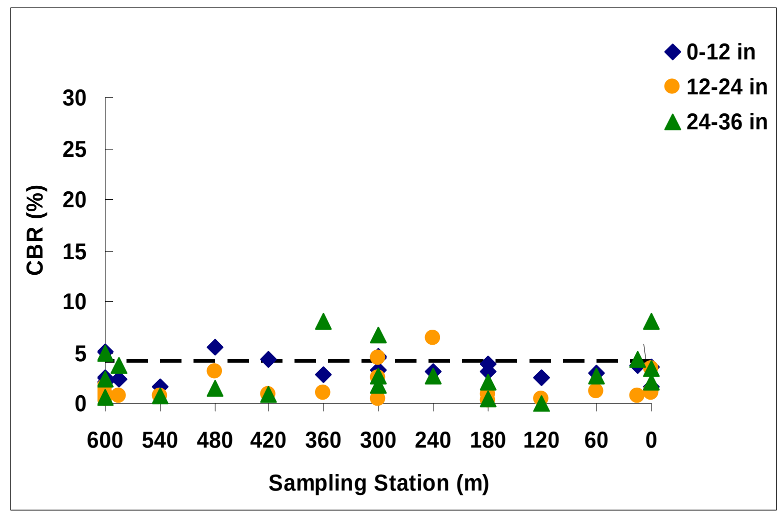
5-20a. Spring.



5-20b. Summer.

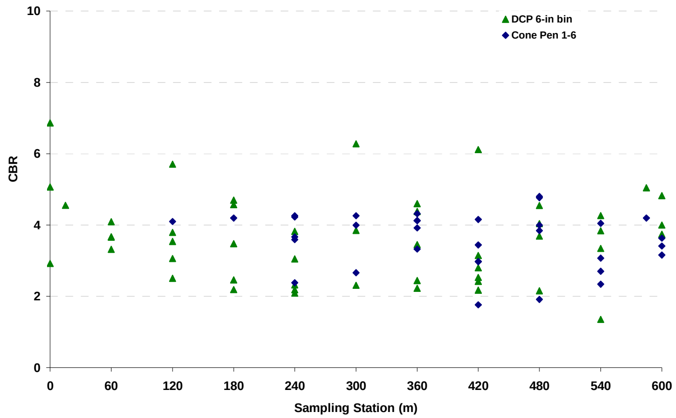


5-20c. Fall.

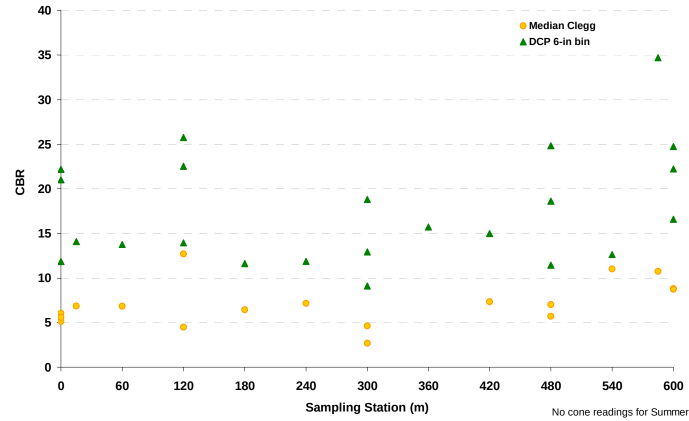


5-20d. Winter.

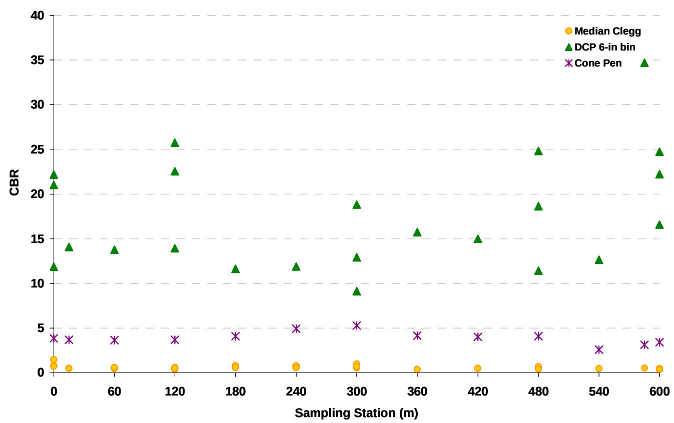
Figure 5-20. Comparison of DCP data for all IOPs.



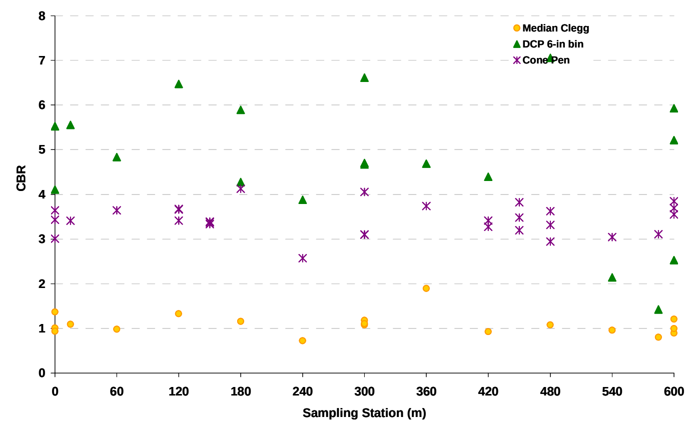
5-21a. Spring.



5-21b. Summer.



5-21c. Fall.



5-21d. Winter.

Figure 5-21. Upper soil surface strength measurements at the Ford Farm RAS for all IOPs.

Organic content

At the Ford Farm RAS, organic content testing was done on the surface samples collected at these soil pit locations: Stations 84 m Centerline (the rutted, muddy area—both the wet and dry sides, 120 m 2 m West, 180 m 2 m East, 300 m Centerline, 420 m 2 m West, and 480 m 2 m East. The results of the organic contents for the Ford Farm are summarized in Table 5-5. The “Average” column provides the average for only the repeat samples. The average organic content by weight for all of the surface samples was 1.15%. Variability between repeat samples was as much as 28% for Station 120 m 2 m West, and as low as 4% at Station 480 m 2 m East. The variability between the stations and the average ranged from 4% to 30%, with the organic content of 1.5% at Station 120 m 2 m West being the highest value.

These organic content results were compared to a range of values published in the 1985 U.S. Department of Agriculture (USDA) Soil Survey of Jefferson County, IN (Nickell 1985). According to the USDA survey, the soil type at the Ford Farm area is classified as a Ryker silt loam resulting in an estimated organic content range of 1—4% (shown by the heavy dashed lines in Fig. 5-22) by weight for the surface layer. Given this range of values, the organic content reported from the ERDC laboratory falls on the lower side of this range.

5.4 Seasonal discussion

As shown in Figure 5-20, the soil strength values for spring, fall, and winter IOPs consistently do not meet the minimum strength requirement. Only during the summer IOP2 do the upper layers of soil show strength values high enough to potentially support aircraft operations. Using Figure 3-10 to determine the number of potential aircraft passes shows that the surface soil strength during summer IOP2 meets the minimum required CBR, with the lowest average CBR value of 15 occurring at Station 600 m. A 12-in.-thick layer of soil overlaying the layer of average CBR 15 at the 12- to 24- in. depth, results in approximately 100 passes.

Table 5-5. Summary of organic content testing for Ford Farm RAS, April 20, 2005.

Test Group	Sample Location	Wet Weight	Tare Weight	Dry Weight	Dry Soil	Water Weight	Moisture Content	440°C	Ash	Organic Content	Average
		(g)	(g)	(g)	(g)	(g)	(%)	(g)	(%)	(%)	(%)
1	120 m 2 m West	115.7	63.7	114.8	51.2	0.9	1.7	113.1	98.5	1.5	
3	120 m 2 m West (repeat 1)	109.0	76.4	108.6	32.2	0.4	1.2	107.5	99.0	1.0	
5	120 m 2 m West (repeat 2)	101.9	73.2	101.7	28.5	0.2	0.8	100.6	99.0	1.0	1.17
5	180 m 2 m East	134.8	76.4	123.1	46.7	11.7	25.0	121.9	99.0	1.0	
1	300 m Centerline	119.4	68.3	117.7	49.4	1.7	3.5	116.4	98.9	1.1	
2	300 m Centerline (repeat 1)	126.5	67.4	124.7	57.3	1.8	3.2	123.0	98.7	1.3	1.22
5	420 m 2 m West	157.8	83.0	143.1	60.1	14.7	24.5	141.4	98.8	1.2	
2	480 m 2 m East	237.3	131.8	213.3	81.5	24.0	29.4	210.9	98.9	1.1	
3	480 m 2 m East (repeat 1)	150.0	83.0	135.8	52.8	14.2	26.9	134.2	98.9	1.1	
4	480 m 2 m East (repeat 2)	134.1	73.2	120.8	47.6	13.4	28.1	119.3	98.8	1.2	1.15
2	84 m Centerline (muddy, dry side)	114.8	64.0	114.3	50.3	0.5	1.0	113.0	98.9	1.1	
2	84 m Centerline (muddy, wet side)	121.3	68.6	120.8	52.2	0.5	1.0	119.4	98.9	1.1	

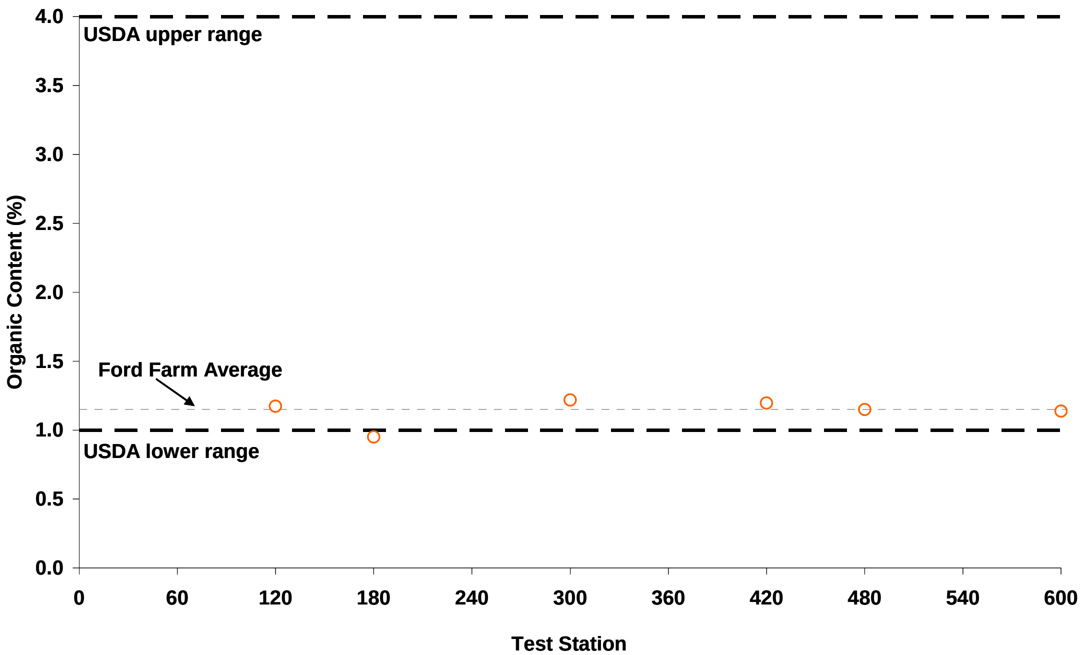


Figure 5-22. Organic content shown at Ford Farm RAS testing stations as compared to the average value of all organic surface samples.

6 Seasonal Analysis

A goal of the OLS program is to determine the ability of the software to locate smooth, flat, and obstruction-free landing sites seasonally. There are two components of the seasonal concept. One involves identifying a season in each climate when the most OLSs are available and using that information to create a strategic OLS inventory. The second concept involves assessing the seasonal capability of the OLS software to accept or reject OLS areas as acceptable.

The first concept involves using a Landsat image taken at a location during one season to locate OLSs, and then to determine if the OLSs found during that season are valid for all seasons. In this manner, except for land-use changes, it would not be necessary to use current Landsat images to inventory potential OLSs for an area of interest. However, such an inventory concept may not be useful where OLS quality, and thus numbers, change dramatically within a region depending on the season, such as in agricultural areas. The concept requires assessing the time of year when most OLSs appear in various geographical areas, assuming that OLS availability is a function of a seasonal component such as greenness. The OLS inventory created from such a search for regions may be of strategic value, but the utility of such a list is dependent on the number of OLSs found at the same locations each season and on minimal changes in land cover over time. Tactically, the validity of such a list is also dependent upon daily weather changes affecting soil moisture and, therefore, soil strength.

The second seasonal concept involves evaluating the ability of the software to locate successful OLSs on images each season; that is, the capability of the software may be seasonally dependent and may be more sensitive to some factors affecting OLS quality in some seasons.

These seasonal concepts were evaluated using only the OLS software written to locate smooth, flat, and obstruction-free locations. Soil moisture and soil strength algorithms had not yet been integrated into the software. Soil strength alone could cause an OLS that is acceptable one season to be rejected during another, even if other factors did not change.

6.1 OLS software seasonal consistency

Strategic utility of the OLS software is dependent, as described above, on its ability to consistently select high-quality OLSs each season. This is a function of the software's accuracy each season, as described below, but also on the seasonal consistency of the region, as described above. Developing a strategic inventory of OLSs in regions that do not change seasonally in ways that affect the quality of OLSs may be more useful than developing an inventory in areas that do change seasonally.

One measure of seasonal OLS consistency may be considered as the number of OLSs that are mapped within a Landsat image each season. A consistent number of OLSs located by the software each season within a Landsat image may suggest that the software is locating the same OLSs each season. However, this actually may not be true. Although the number of OLSs each season may be similar, the locations of OLSs within that image may be different. Therefore, 2,000 OLSs located within an image during the spring may not be in the same locations as 2,000 OLSs located in a Landsat image of the same area the following summer. It would be useful to know the proportion of OLSs that are consistently located at the same place each season.

Based on techniques demonstrated by Haren (2005) while assessing the seasonal accuracy of the OLS software at each RAS, ERDC also tabulated the number of OLSs located per season in each Landsat image. Figure 6-1 shows the number of OLSs located in Landsat images in southern Indiana in path 20, row 33 during the months of April, August, and November 2005, and April 2006 (Table 6-1). Two versions of the Boeing OLS software were assessed, Version 7 released March 28, 2005 and Version 10 released March 12, 2007 (Almassy and Blake 2005, 2006). Version 7 of the software was used to initially locate the RAS field sites, and Version 10 of the software is the last official software release in fiscal year 2007.

Figure 6-1 and Table 6-1 show that many more OLSs are located by both versions of the software with the November Landsat image than with the other images. Although the four seasons are only represented by four points in time, they do show the general trends. We did not obtain greenness indices for each of the images. However, images analyzed by Haren (2005) in a preliminary analysis showed that the number of OLSs de-

creases as the greenness index threshold in the software is raised. That is, higher software-specified greenness index thresholds cause areas that are too green to be omitted as candidate OLS locations. In effect, the same process is occurring seasonally. When the software is executed each season at the same greenness index, areas that display a larger greenness index, especially during warmer and more moist months, will tend to be omitted as candidate OLS locations.

The large variation in numbers of OLSs by season—ranging from 13 to 19,874 for software Version 7 and from 0 to 7,789 for software Version 10—is an expression of large seasonal variation in factors that affect OLS quality. In Indiana, this may be due to vegetation changes with season.

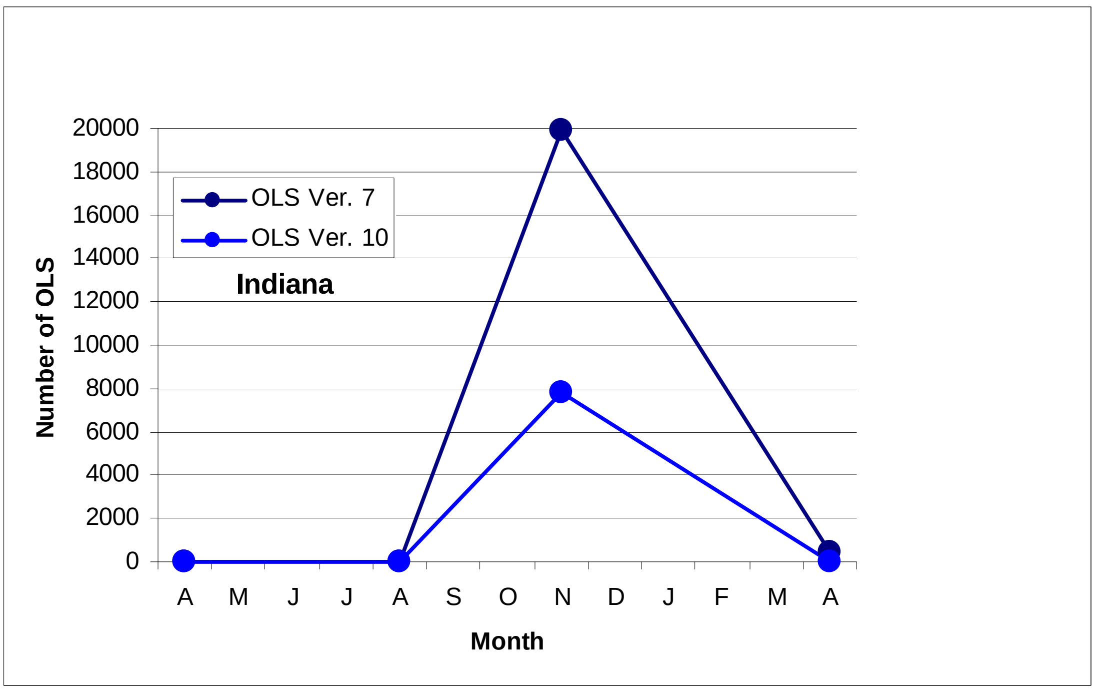


Figure 6-1. Number of OLSs located seasonally, by software version.

We also assessed the frequency of OLSs plotted in the same location from season to season in Indiana. Although the small number of OLSs reported by Version 10, except in November, and by Version 7 in April and August 2005, may preclude the necessity of such an analysis (Table 6-1), we conducted the analysis using both versions of the software.

The OLS software provides coordinates for the center point and the direction for each OLS. Using those coordinates and directions, we compared OLS locations for every combination of seasons within a software version. Table 6-1 shows the number of OLSs compared during each season.

The analysis found no occurrences of matching OLS coordinates between any seasons. However, this may not be a true indicator that OLSs are not located at the same location each season. Each Landsat image is unique with regard to its georegistration to the earth's coordinate system. As a result, it is possible that any two pixels in similar relative positions in Landsat images taken during different seasons would have different earth-referenced coordinates. Even the same image georeferenced to the earth by two different processes or individuals may produce different earth coordinates for any single pixel.

Therefore, there is still a possibility that OLSs may be located in nearly the same location for more than one season. Definitive demonstration of this will require overlaying of seasonal, georeferenced images within a geographic information system.

Table 6-1. Number of OLSs located seasonally, by software version.

Image	Date	Version 7	Version 10	Notes*
Path 20 Row 33	April 18, 2005	13	5	No OLSs in cloud
Path 20 Row 33	August 25, 2005	26	0	No cloud
Path 20 Row 33	November 12, 2005	19,874	7,789	No cloud
Path 20 Row 33	April 5, 2006	450	0	No cloud
*Comparisons were made only with Landsat images where OLSs were not plotted in clouds. OLSs can be plotted in clouds in OLS software Version 7; software Version 10 excludes cloudy areas for locating OLSs.				

6.2 OLS software seasonal accuracy

Field work at the Indiana sites was scheduled to assess the quality of OLSs with season. Field work was conducted in April 2005 (spring IOP1), August 2005 (summer IOP2), October/November 2005 (fall IOP3), and February/March 2006 (winter IOP4). The field team assessed the terrain features of the selected RASs according to criteria previously described in Section 3.3 "Assess terrain characteristics."

We also used Versions 7 and 10 of the OLS software to plot the seasonal location of OLSs in the same vicinity as the location of the OLSs that were used to start the field work at North Vernon Municipal Airport and at Ford Farm. The initial field sites were located using Version 7 of the software with a March 17, 2005 image. Those locations are shown in Figure 6-2 for the North Vernon Municipal Airport site. In the figure, the OLSs are denoted in transparent blue. The North Vernon Airport RAS, one OLS in the cluster, is outlined in yellow with dots at end points. Figure 6-3 shows the locations for the Ford Farm site, again denoted in transparent blue. The Ford Farm RAS, one OLS of a pair, is outlined in yellow with dots at end points. The Landsat images used for analysis were georeferenced at the USGS precision level and overlaid over a georeferenced orthophotoquad.

Figure 6-4 illustrates the North Vernon Airport RAS location selected with a Landsat image of March 17, 2005 using OLS software Version 7 overlaid onto the seasonal Landsat images from April, August, and November in 2005, and April 2006 (Table 6-1). No OLSs were selected within the vicinity of the North Vernon Municipal Airport site in any of the five seasonal images using OLS software Version 7 or OLS software Version 10. Reasons for this are unknown and, unless a full analysis of pixel spectral values is accomplished, we can only speculate why OLSs were not selected. In April the RAS was clear, tilled, and ready to plant (Fig. 6-4a). Figure 6-4a, however, shows considerable variation of spectral signature in the bands used here for illustration—bands 1, 2, and 3. Because the RAS was tilled and planted and emergence may have only started, the green index probably did not cause rejection of the site; the flatness index, however, may have caused rejection because of the pixel-to-pixel variation in reflectance. In addition, wet areas near drainage ditches may have been a factor in rejecting the location for OLSs.

Figure 6-4, b and c, both imaged in August, show high green values that result from the roughly 2.5-m corn crop covering the field at that time. It also shows considerable interpixel variation. Therefore, the greenness index and the flatness index both may have contributed to the software appropriately rejecting the site for locating OLSs. Figure 6-4d was imaged in November after harvest, and the field was relatively clear except for

corn plant debris. An OLS was likely not located at the airport in November because the Landsat image was cut causing the flatness index to exclude the area from consideration.

Figure 6-4e in April 2006 appears to be ideal for OLS selection—at least to the eye. It is unclear why the site was rejected, considering the apparent low greenness and the relatively small change in pixel-to-pixel reflectance, at least in bands 1, 2, and 3. However, as indicated earlier, drainage ditches with standing water may have caused the site to be rejected.

Figures 6-5 and 6-6 illustrate Landsat pixels for seasonal images at the Ford Farm RAS selected with a March 17, 2005 Landsat image using OLS software Version 7. As with the North Vernon Municipal Airport site, no OLSs were selected near the Ford Farm in any of the five seasonal images using OLS software Version 7 or software Version 10. Again, reasons for this are unknown.

Figures 6-5, a and d, and 6-6 are images of the Ford Farm site taken in April 2005, November 2005, and April 2006 when the soil surface was barren of green vegetation. During these dates the greenness index could not have caused the site to be rejected for OLSs because green vegetation was not present. However, there was a wet spot—possibly a spring—on the site that could have caused free water to be visible and, therefore, the site was rejected. Alternatively, or in addition, pixel-to-pixel brightness variation may have caused the flatness index to reject each site.

Figure 6-5, b and c, shows both August 2005 images taken when the corn crop was over 2-m high. The greenness of the majority of pixels is possibly a cause for the site to be rejected as an OLS in August. In addition, high pixel-to-pixel variation in reflectivity due to large spatial variations in corn crop growth in the field (Fig. 6-7) may have also caused the flatness index to reject the site during August 2005.

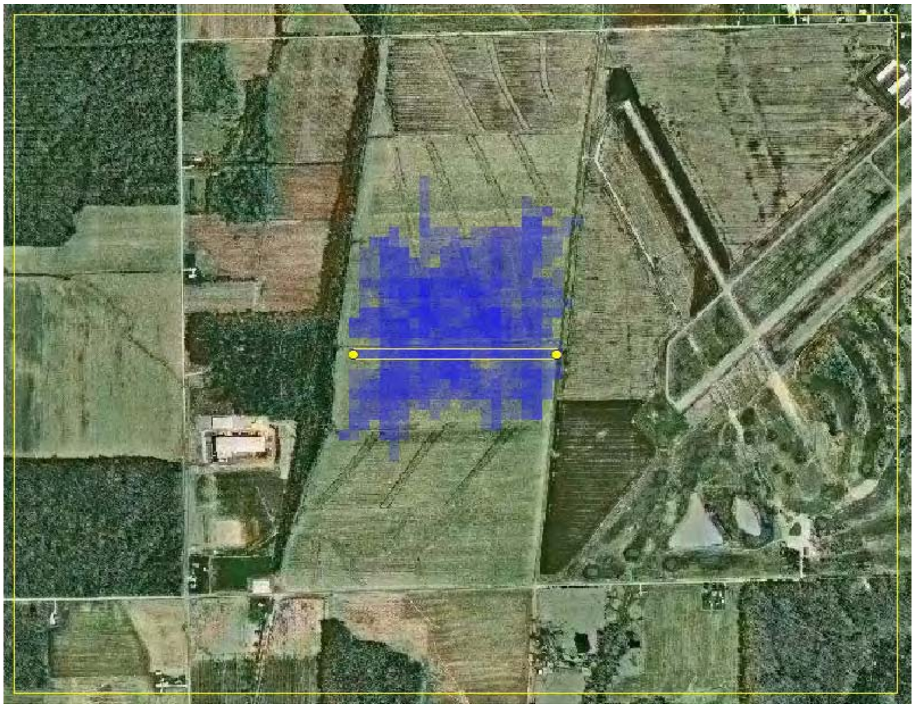


Figure 6-2. Cluster of OLSs around North Vernon Municipal Airport site.

Figure 6-3. Two parallel OLSs located on Ford Farm.

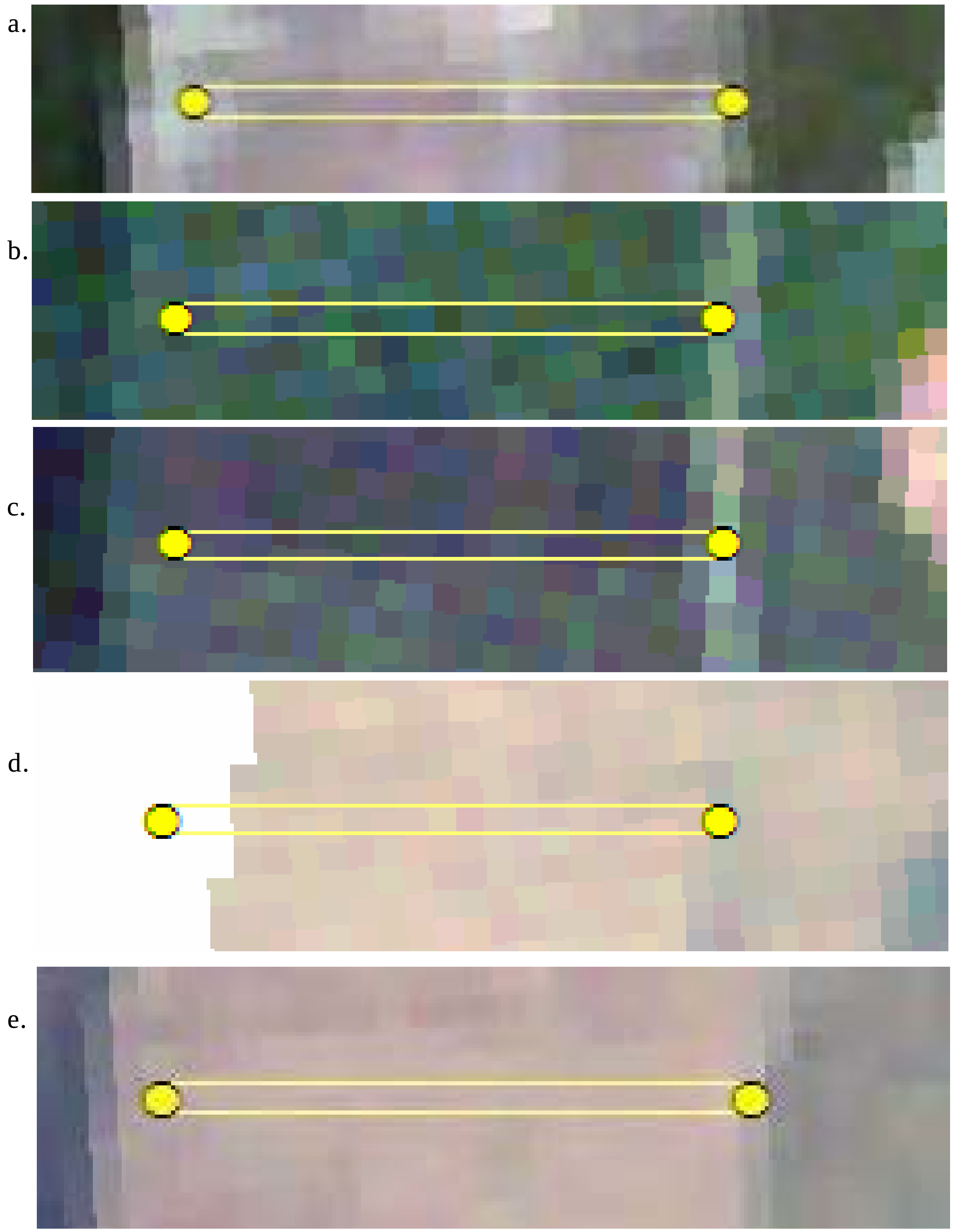


Figure 6-4. Location of North Vernon Airport RAS from Landsat image of March 17, 2005, overlaid onto Landsat images from (a) April 18, 2005, (b) August 8, 2005, (c) August 24, 2005, (d) November 12, 2005, and (e) April 5, 2006.

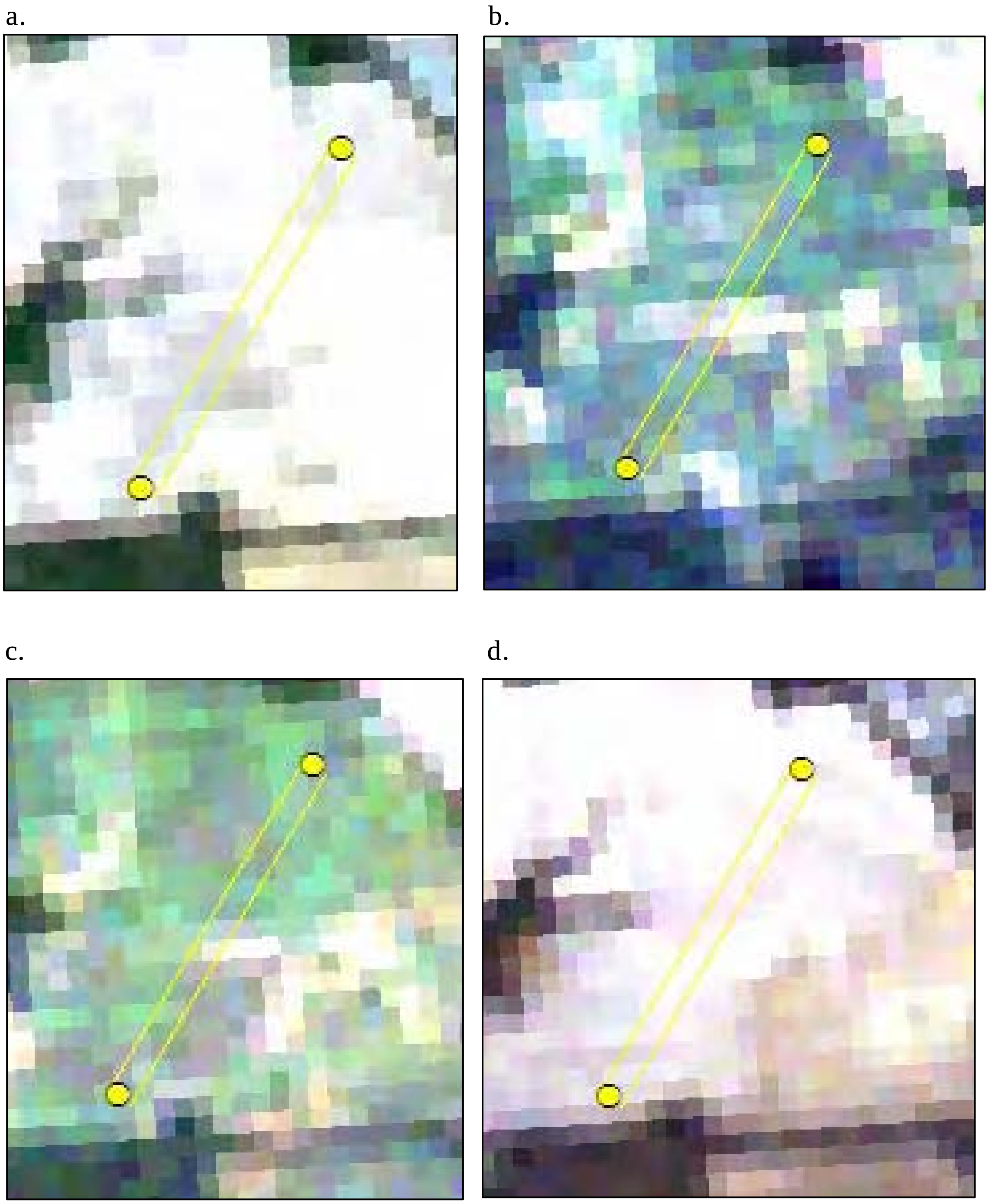


Figure 6-5. Location of North Vernon Airport RAS from Landsat image of March 17, 2005 overlaid onto Landsat images from (a) April 18, 2005, (b) August 8, 2005, (c) August 24, 2005, and (d) November 12, 2005.

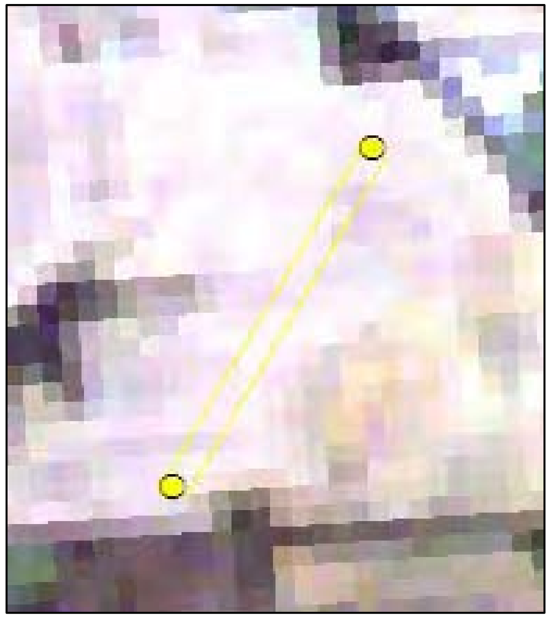


Figure 6-6. Location of North Vernon Airport RAS from Landsat image of March 17, 2005 overlaid onto Landsat image from April 5, 2006.

With respect to terrain characteristics, both the North Vernon Airport RAS and the Ford Farm RAS generally pass most criteria, especially those criteria that do not vary significantly with season. Being agricultural sites planted with corn, they do fail due to vegetation cover during the summer months. They may also fail due to standing water. Soil strength may also eliminate them, but is not affected by the version of OLS software tested.

It is unclear why Version 7 of the Boeing OLS software did not locate OLSs at the airport site or the Ford Farm site in the April or November Landsat images. However, indications are that software Version 10 is more discriminating in selecting OLSs, based on the smaller number of OLSs located on any given image by Version 10 than by Version 7. Version 10 also did not select OLSs at the field sites when executed with the March 17, 2005 Landsat image used to select the original field sites with Version 7 of the software. Therefore, if software Version 10 had been available in March 2005, our field sites would not have been located at the North Vernon Municipal Airport site, nor at the Ford Farm site.

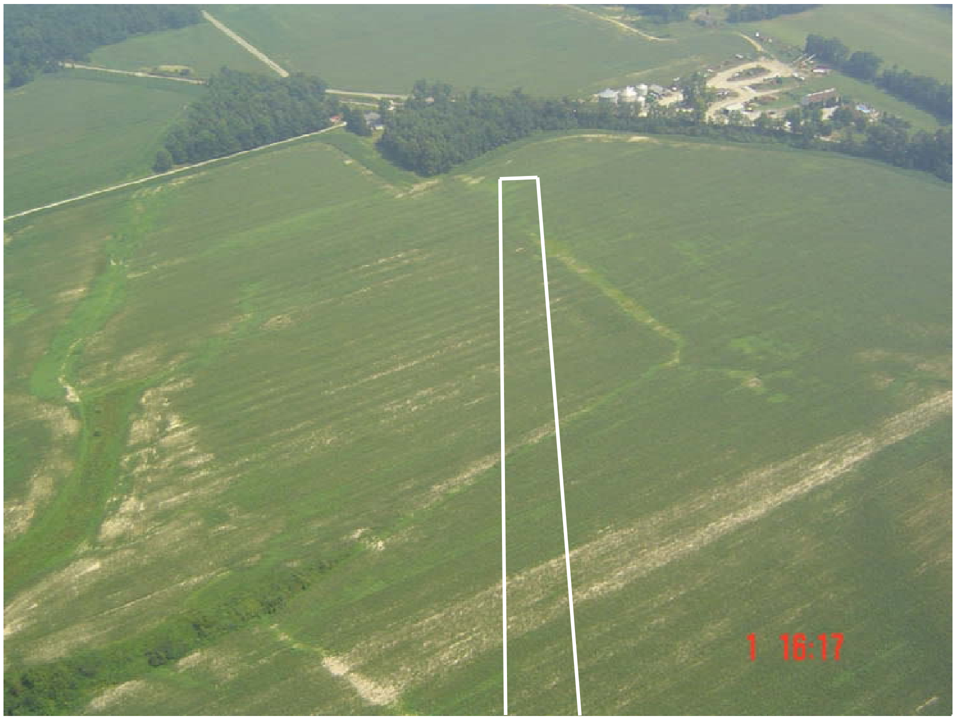


Figure 6-7. Approximate position of Ford Farm OLS illustrating corn growth patterns in August 2005.

7 SAS Sites

7.1 Site description

All four of the soil analysis sites were located in Butlerville, IN. Three SAS locations were at SEPAC, and the fourth SAS was located at the MUTC on land adjacent to SEPAC operated by the Indiana National Guard. Figure 7-1, a–c, shows the locations of the sampling points on orthophoto imagery at each SAS. The Wilbur and Cincinnati soil types were located across the street from each other (Fig. 7-1b).

The intent of the SAS locations was to evaluate soils that are dissimilar to those at the RAS locations to expand the number of soils characterized beyond the soils at the RAS locations. The common names of the soils at the SAS locations were Cobbsfork, Cincinnati, Parke, and Wilbur (Fig. 7-2, a–d). The SAS locations of soils in Figure 7-2 a, b, and d, were at SEPAC; the Parke soil (Fig. 7-2c) was at MUTC. The photographs in Figure 7-2 were taken during spring IOP1 and show the SAS conditions. Table 7-1 lists all of the measurements collected at the SAS during each IOP.

7.2 Field testing

7.2.1 Nonseasonal conditions

This section describes the soil field measurements collected at the SAS locations that should not be affected by seasonal change. The same methods used at the RAS locations were used at the SAS locations, although, again, the SAS locations were not evaluated as comprehensively as the RAS locations. This section covers soil texture, soil color, and soil density.

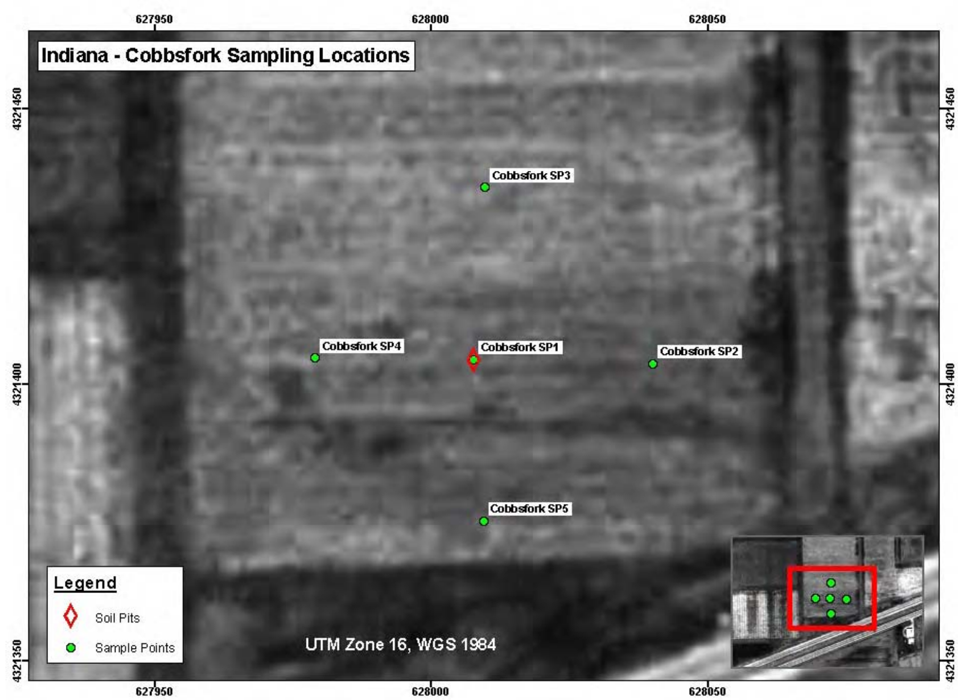
Soil characteristics

Photographs of the surface condition during the spring IOP1 at each soil pit location are shown in Figure 7-3, a–d. Grain size analysis plots for each soil type are shown in Figures 7-4–7-7. The plasticity characteristics are plotted in Figure 7-8. Physical soil properties from the soil pit from each SAS are summarized in Table 7-2. In general, the USCS soil classification is a lean clay (CL) with a percentage of fines in excess of 70% at all sites. The Cincinnati soil is a full-depth CL containing some sand; the Cobbsfork material is a full-depth CL; the upper 150 mm of the Parke soil classifies as

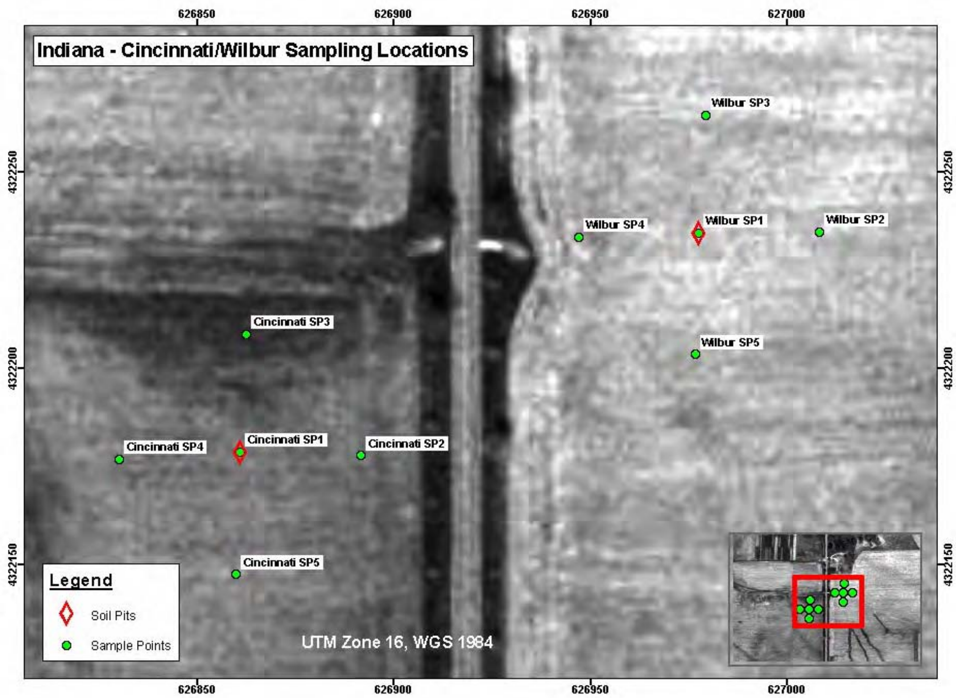
a silt material (ML) overlying CL; and the Wilbur soil is also a full-depth CL. From an engineering standpoint, the soils exhibit very similar characteristics. Photographs in Figures 7-9–7-12 show the soil pits excavated at each SAS location.

Soil color

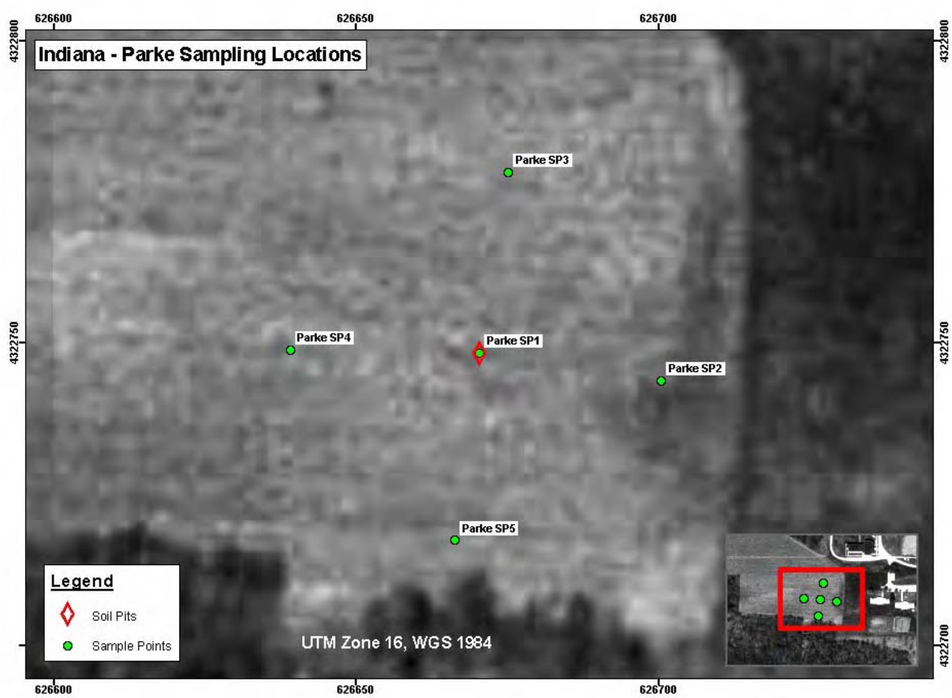
The Munsell color chart (Rock-Color Chart 1991, Geological Society of America) was used for identification. The rock chart was used because it is a simplified version of the GSA soil color chart. Table 7-3 summarizes the colors identified during the spring IOP, with the exception of the Cobbsfork soil.



7-1a. Cobbsfork.



7-1b. Cincinnati and Wilbur.



7-1c. Parke.

Figure 7-1. SAS sampling locations overlaid in orthophoto imagery.

7-2a. Cobbsfork.

7-2b. Cincinnati.

7-2c. Parke.

7-2d. Wilbur.

Figure 7-2. View looking northward of SAS soil test areas (spring IOP1).

Table 7-1. Soil field measurements taken at the SAS locations during each season.

DCP = Dynamic Cone Penetrometer (Strength Profile)
Clegg = Clegg Hammer (Surface Strength)
Army Cone = Cone Index (Strength Profile)
Dor Cone (Surface Strength)
Dynamax = Soil Moisture (Surface and/or with depth)
S = Soil sample(s) taken
D = Density (Density using Troxler and/or Density using drive cylinder)
V = Vegetation Cover (images)

x indicates that a measurement was taken

	SPRING05								SUMMER05								FALL05								WINTER06							
Sampling points	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V
Cincinnati SP1	x				x	x	x	x	x				x	x			x	x			x			x	x	x			x			x
Cincinnati SP2	x								x				x				x	x			x				x	x			x			
Cincinnati SP3	x								x				x				x	x			x				x	x			x			
Cincinnati SP4	x								x				x				x	x			x				x	x			x			
Cincinnati SP5	x								x				x				x	x			x				x	x			x			
Cobbsfork SP1					x	x	x	x	x	x			x	x		x	x	x			x			x	x	x			x			x
Cobbsfork SP2	x								x	x			x				x	x			x				x	x			x			
Cobbsfork SP3	x								x	x			x				x	x			x				x	x			x			
Cobbsfork SP4	x								x	x			x				x	x			x				x	x			x			
Cobbsfork SP5	x								x	x			x				x	x							x	x			x			
Parke SP1	x				x	x	x	x	x	x			x	x		x	x	x			x			x								
Parke SP2	x								x	x			x				x	x			x				x	x			x			
Parke SP3	x								x	x			x				x	x			x											
Parke SP4	x								x	x			x				x	x			x											
Parke SP5	x								x	x			x				x	x			x				x	x			x			x
Wilbur SP1	x				x	x	x	x	x	x			x	x			x	x			x			x	x	x			x			x
Wilbur SP2	x								x	x			x				x	x			x				x	x			x			
Wilbur SP3	x								x	x			x				x	x			x				x	x			x			
Wilbur SP4	x								x	x			x				x	x			x				x	x			x			
Wilbur SP5	x								x	x			x				x	x			x				x	x			x			

7-3a. Cobbsfork soil.

7-3b. Cincinnati.

7-3c. Parke.

7-3d. Wilbur.

Figure 7-3. In situ surface conditions at each of the SAS soil pit locations.

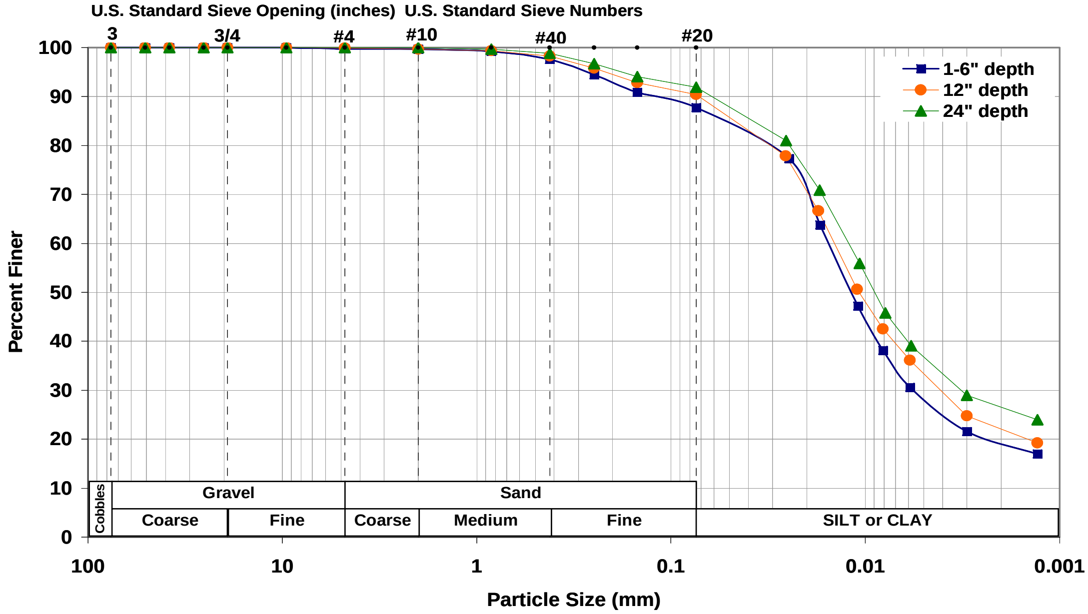


Figure 7-4. Summary of soil classification for the Cobbsfork soil at each depth 0.6-m (2-ft) soil pits.

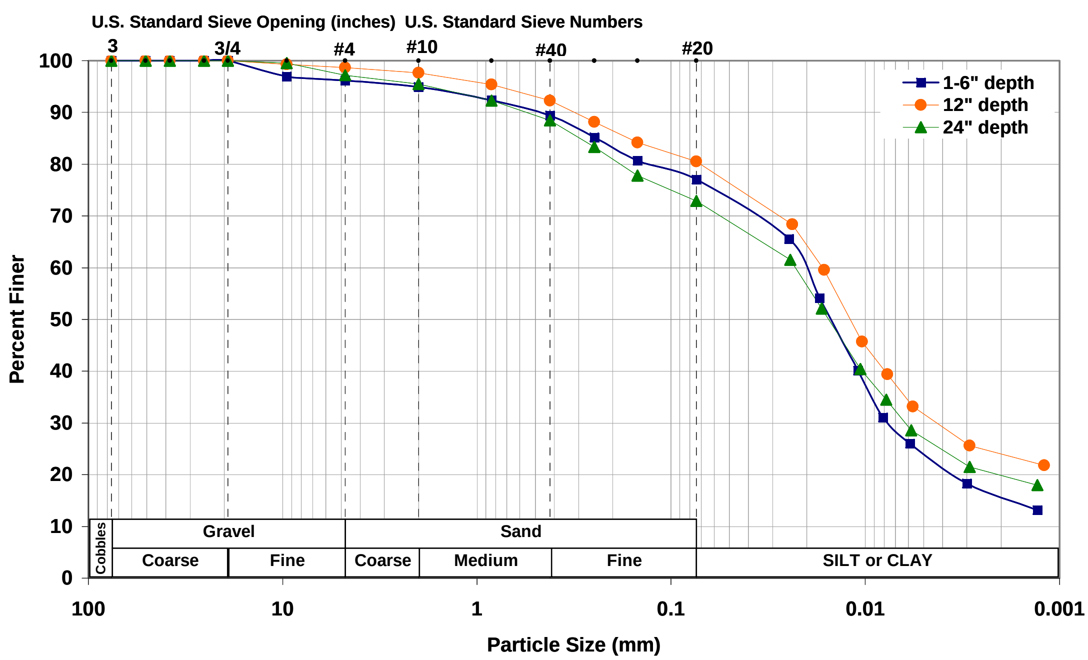


Figure 7-5. Summary of soil classification for the Cincinnati soil at each depth 0.6-m (2-ft) soil pits.

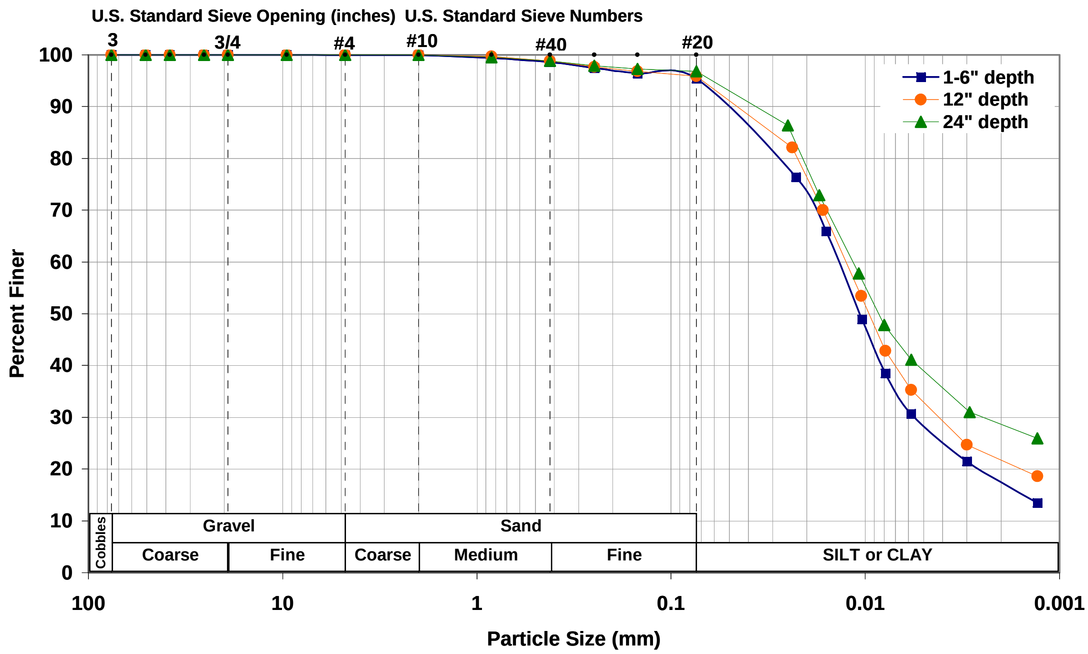


Figure 7-6. Summary of soil classification for the Parke soil at each depth 0.6-m (2-ft) soil pits.

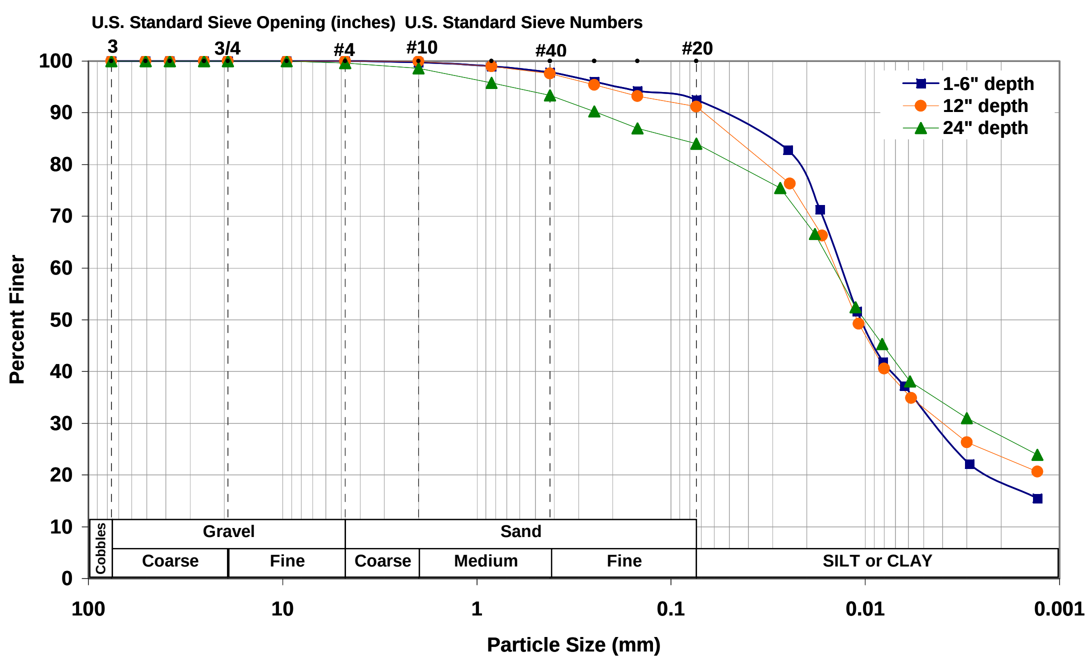


Figure 7-7. Summary of soil classification for the Wilbur soil at each depth 0.6-m (2-ft) soil pits.

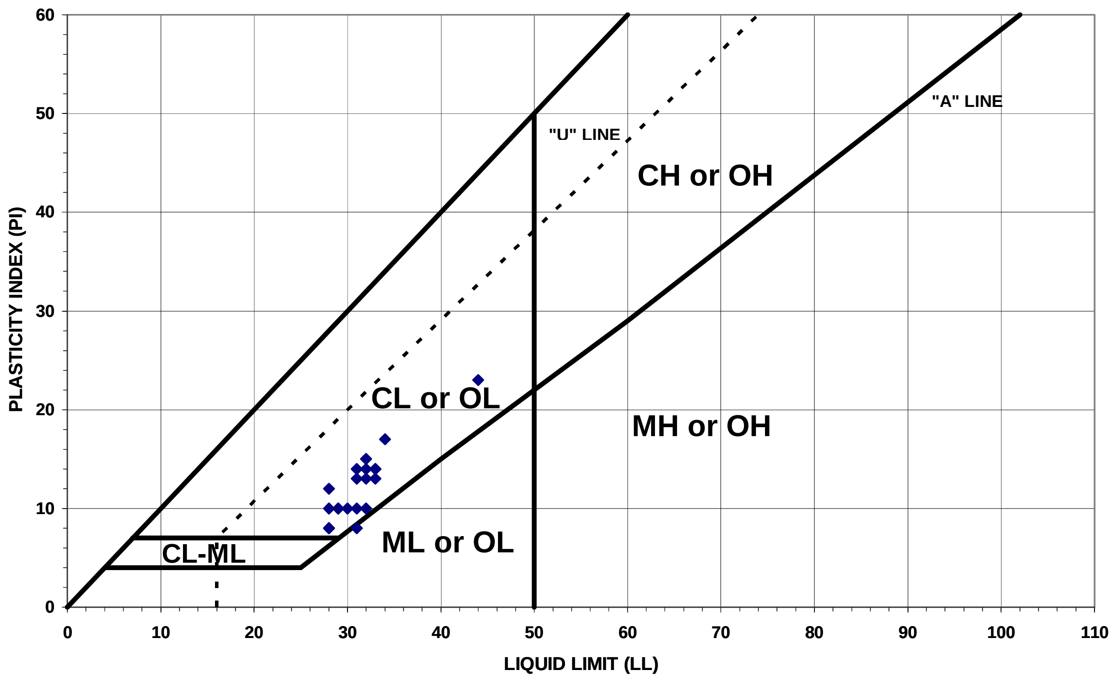


Figure 7-8. Plasticity chart for soil samples from SEPAC and MUTC SAS.

Table 7-2. Summary of physical soil properties at the SEPAC and MUTC SAS.

Soil Type	Sampling Station																			
	Cincinnati					Cobbsfork					Parke					Wilbur				
Depth below surface	25–152 mm (1–6 in.)	305 mm (12 in.)	610 mm (24 in.)	305–610 mm (12–24 in.)	610–810 mm (24–32 in.)	25–152 mm (1–6 in.)	305 mm (12 in.)	610 mm (24 in.)	305–610 mm (12–24 in.)	610–810 mm (24–32 in.)	25–152 mm (1–6 in.)	305 mm (12 in.)	610 mm (24 in.)	305–610 mm (12–24 in.)	610–890 mm (24–31 in.)	25–152 mm (1–6 in.)	305 mm (12 in.)	610 mm (24 in.)	305–610 mm (12–24 in.)	610–840 mm (24–33 in.)
Season sample collected	Spring			Summer		Spring			Summer		Spring			Summer		Spring			Summer	
USCS soil description	CL Lean clay w/sand					CL Lean clay					ML Silt	CL Lean clay				CL Lean clay				
Liquid limit	29	33	32	29	33	28	28	31	28	28	31	31	44	32	33	30	31	34	32	32
Plasticity index	10	14	15	10	14	8	12	14	8	10	8	10	23	10	13	10	13	17	14	13
% Fines	77	80.5	72.9	77.0	80.5	87.8	90.4	91.9	87.8	91.3	95.4	95.9	96.8	96.4	95.5	92.5	91.2	84.0	90.6	85.9
Specific gravity	2.58	2.62	2.64	2.58	2.62	2.57	2.61	2.58	2.57	2.58	2.60	2.60	2.59	2.61	2.63	2.61	2.58	2.58	23.30	2.64

Figure 7-9. Cincinnati soil pit, upper 300 mm.

Figure 7-10. Cobbsfork soil pit, upper 600 mm.

Figure 7-11. Parke soil pit, upper 600 mm.

Figure 7-12. Wilbur soil pit, upper 600 mm.

Table 7-3. Summary of Munsell soil color identification at SEPAC and MUTC SAS.

	Sampling Station			
	Cincinnati	Cobbsfork	Parke	Wilbur
Season sample collected	Spring			
Munsell color identification	10 yr 5/4 Moderate yellowish brown		10 yr 5/4 Moderate yellowish brown	10 yr 5/4 Moderate yellowish brown

Soil density

Concurrent with digging soil pits, soil density was measured with the Troxler nuclear density gauge. Density readings were taken to approximately 900 mm (36 in.) in the 0.6-m (2-ft) soil pit. No free water was encountered during the excavation of the SAS soil pits, unlike the experience at the RAS locations. The calculated soil dry density values for all of the SAS locations are shown in Figure 7-13. In general, the range of soil dry density values are similar to both the North Vernon Airport and Ford Farm RASs.

7.2.2 Seasonal conditions

Characteristics of the SAS locations that may show changes due to seasonal influences will be discussed in this section. Field measurements taken during each IOP focused on soil moisture and soil strength. Soil samples collected from the surface during the spring IOP were also analyzed for organic content.

Unlike the RAS locations, the SAS test areas were regularly plowed and intentionally kept clear of any significant vegetation growth. The condition of the soil surface during each IOP was photographed, but not assessed as rigorously as the RAS locations.

Surface condition

The SAS locations were cleared before each field visit; therefore, the difference in the surface condition remained consistent during each IOP. In the spring, vegetation residue was present before any disturbance from field activities. During the fall, the consistency of the surface from plowing shows clumps of soil on the surface, depending on the characteristics of the type of soil. During the winter, the surface at all four of the SAS locations is dried and cracked consistently.

Soil moisture

Measurements made with depth to capture the volumetric moisture content during each IOP are summarized in Figures 7-14, a–d. The plots show the median value of the measurements made in the field. Measurements made during the spring IOP were taken with the Dynamax ML2 probe during excavation of the soil pits in the same manner as soil measurements on the RAS. Moisture measurements during the summer, fall, and winter IOPs were taken in the vicinity of the soil pit location using the gas-powered auger. At the remaining four test points only surface moisture readings were recorded. The exception occurred at the Parke soil during the winter IOP. The area containing the test points had been reclassified as an archeologically sensitive area during the time between the fall and winter field visits. This reclassification removed test points 1, 3, and 4 from testing. Test points 2 and 5, east and south, respectively, fell outside the designated site and moisture readings were collected at both locations during the winter IOP. In addition, the calculated volumetric moisture content values converted from the gravimetric moisture content values from the soil samples collected during the spring IOP are included on the same plot as the median values. The median volumetric moisture content values for the four SAS soils for the spring IOP1 are summarized in Table 7-4.

Soil strength

The DCP was used to produce a profile of the strength of the soil with depth during each IOP. Measurements were taken at each of the five sampling points for each of the four SAS locations. The data were processed using a software program to determine the soil strength with depth in 150-mm 6-in. increments. The strength profiles are given in Figures 7-15, a–d. Tables 7-5–7-8 list the calculated CBR values for each increment at each sampling point.

Upper soil strength measurements were made using the lightweight Clegg hammer during the summer, fall, and winter IOPs. No surface measurements were collected during the spring IOP.

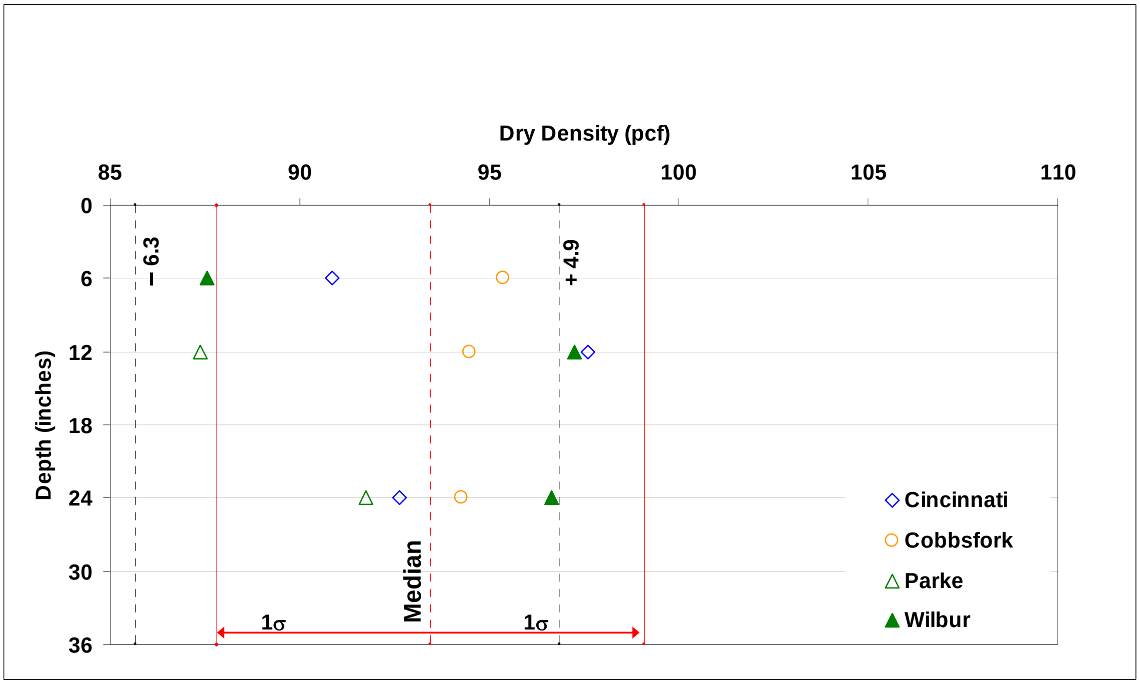
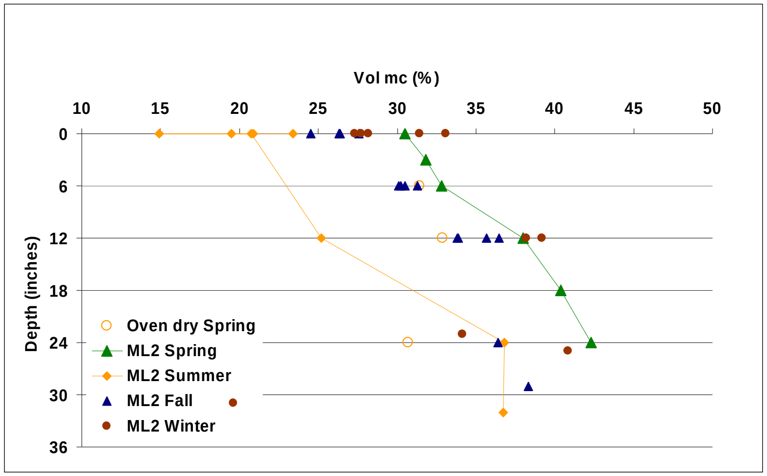


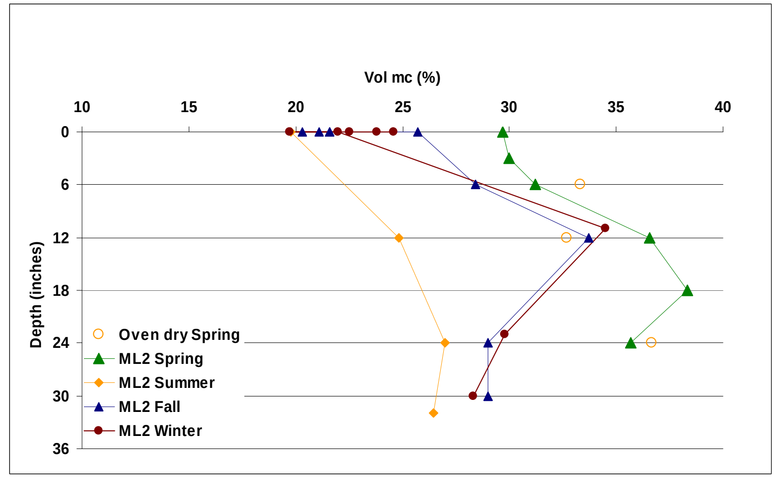
Figure 7-13. Soil dry density values from spring IOP1 at SAS locations.

Table 7-4. Median volumetric moisture content for SAS soils.

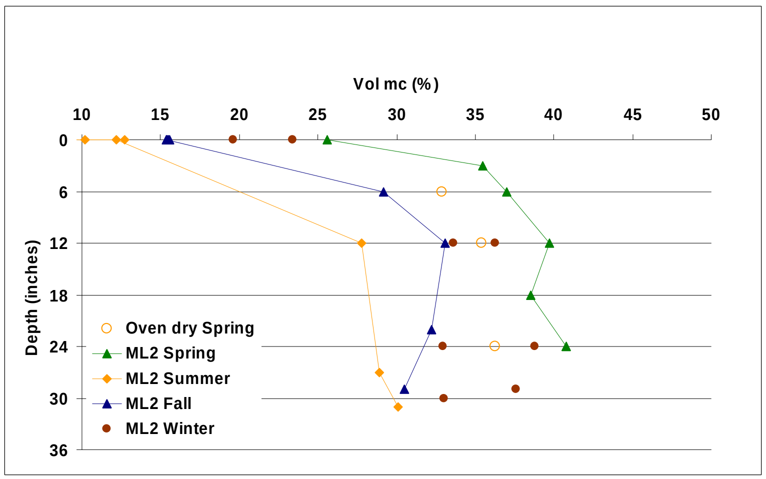
Sampling Station	Depth	Depth	Wet Density	Moisture Content (w)	Dry Density	Dry Density	Calculated Volumetic Moisture Content	ML2 Volumetic Moisture Content (median)
	(in.)	(mm)	(lbs/ft³)	%	(lbs/ft³)	(kg/m³)	%	%
Cincinnati	0	0						29.7
	6	152.4	110.5	21.6	90.9	1,455.6	31.46	31.2
	12	304.8	118	20.9	97.6	1,563.4	32.69	36.6
	18	457.2						38.4
	24	609.6	115.5	24.7	92.62229	1,483.7	36.66	35.7
Cobbsfork	0	0						30.5
	6	152.4	113.3	18.8	95.4	1,527.7	28.7	32.9
	12	304.8	115	21.7	94.5	1,513.7	32.9	38.0
	18	457.2						40.4
	24	609.6	113.4	20.3	94.3	1,510.0	30.7	42.3
	30	762						
Parke	0	0						25.6
	6	152.4	98.2	26.4	77.7	1,244.5	32.9	37.0
	12	304.8	109.5	25.3	87.4	1,399.9	35.4	39.7
	18	457.2						38.5
	24	609.6	114.4	24.7	91.7	1,469.5	36.3	40.8
	30	762						
Wilbur	0	0						32.0
	6	152.4	109.2	24.7	87.6	1,402.7	34.7	34.3
	12	304.8	116	19.3	97.2	1,557.5	30.1	35.5
	18	457.2						36.8
	24	609.6	118.3	22.4	96.7	1,548.2	34.7	37.8



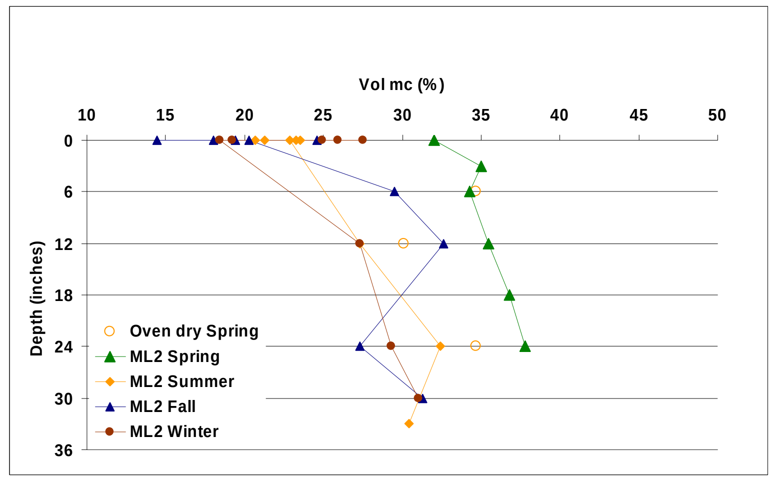
7-14a. Cobbsfork soil.



7-14b. Cincinnati.

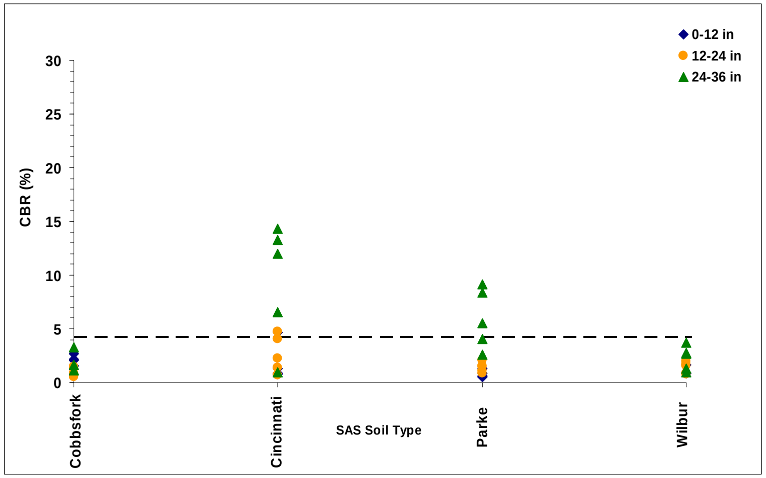


7-14c. Parke.

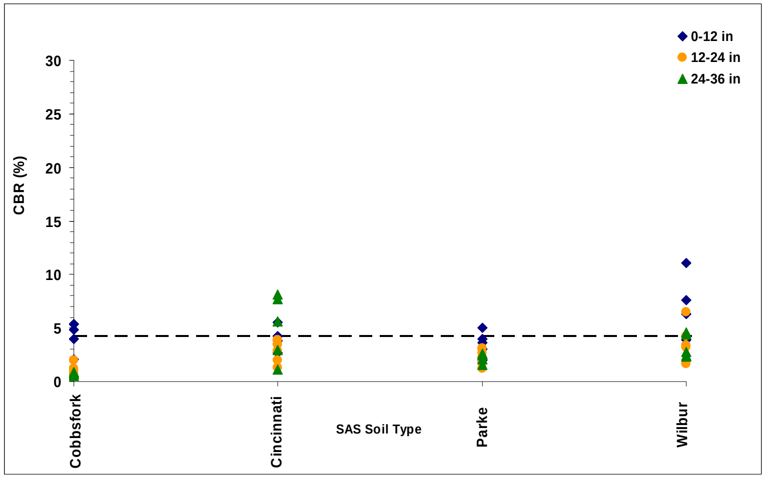


7-14d. Wilbur.

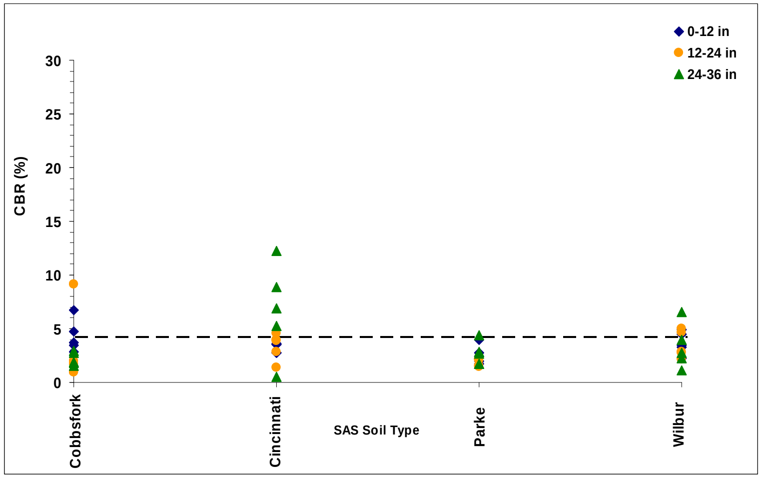
Figure 7-14. Median volumetric moisture content measurements at each SAS soil pit location for all IOPs.



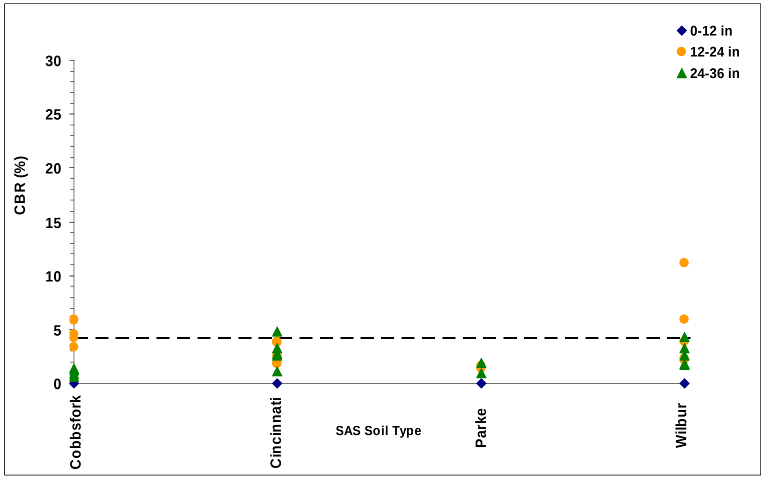
7-15a. Spring IOP1.



7-15b. Summer IOP2.



7-15c. Fall IOP3.



7-15d. Winter IOP4.

Figure 7-15. Average CBR values at each SAS location for all IOPs.

Table 7-5. Summary of average CBR values for SAS locations for spring IOP1.

Station	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
Cincinnati Soil Sampling Point 1	4/21/2005	2.22	3.12	6.30	8.65	9.17	8.28	8.31	2.78	7.31	8.73	8.31
Cincinnati Soil Sampling Point 2	4/21/2005	2.95	4.15	4.92	8.13	8.98	14.40		3.55	6.70	11.99	
Cincinnati Soil Sampling Point 3	4/21/2005	5.56	8.87	2.66	2.31	2.57	3.14		7.22	2.48	2.91	
Cincinnati Soil Sampling Point 4	4/21/2005	1.72	3.38	3.50	3.84	7.10	16.33		2.72	3.67	13.25	
Cincinnati Soil Sampling Point 5	4/21/2005	2.16	3.12	4.32	5.15	8.54	18.19		2.74	4.79	14.33	
Cobbsfork Soil Sampling Point 2	4/21/2005	5.43	5.10	4.01	3.52	3.51	4.51		5.31	3.83	4.01	
Cobbsfork Soil Sampling Point 3	4/21/2005	4.86	4.20	2.97	2.56	2.86	3.62		4.53	2.79	3.20	
Cobbsfork Soil Sampling Point 4	4/21/2005	4.03	3.72	2.37	1.85	2.85	4.17		3.90	2.11	3.22	
Cobbsfork Soil Sampling Point 5	4/21/2005	4.33	5.03	3.32	3.93	5.12	6.96		4.68	3.62	5.91	
Parke Soil Sampling Point 1	4/21/2005	2.05	3.33	2.86	3.80	6.55	12.91		2.85	3.28	10.02	
Parke Soil Sampling Point 2	4/21/2005	2.57	4.35	2.68	2.87	4.04	5.98		3.46	2.79	5.15	
Parke Soil Sampling Point 3	4/21/2005	1.50	2.44	2.57	5.66	7.69	8.73		2.12	3.94	7.95	
Parke Soil Sampling Point 4	4/21/2005	1.76	2.64	3.34	4.44	5.96	7.20		2.27	3.78	6.65	
Parke Soil Sampling Point 5	4/21/2005	1.21	2.58	3.82	5.62	9.63	11.40		2.12	4.62	10.51	
Wilbur Soil Sampling Point 1	4/21/2005	2.23	3.28	4.65	3.45	4.12	6.20		2.75	4.17	5.36	
Wilbur Soil Sampling Point 2	4/21/2005	1.87	3.42	2.37	2.98	3.76	6.41	2.51	2.80	2.67	5.28	2.51
Wilbur Soil Sampling Point 3	4/21/2005	0.74	3.36	2.29	3.09	5.39	7.67		2.83	2.75	6.37	
Wilbur Soil Sampling Point 4	4/21/2005	1.83	5.04	5.33	3.65	2.92	2.99		3.97	4.49	2.95	
Wilbur Soil Sampling Point 5	4/21/2005	2.42	3.11	3.78	3.95	3.62	3.31	3.09	2.77	3.86	3.50	3.09

Table 7-6. Summary of average CBR values for SAS locations for summer IOP2.

Station	Location	Date	Average CBR within 15 cm bins							Average CBR within 30-cm bins			
			0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
Cincinnati Soil Sampling Point 1	Southeastern Purdue Agricultural Center, IN	8/5/2005	4.32	5.91	5.32	6.68	9.57	6.47		5.28	6.07	9.57	
Cincinnati Soil Sampling Point 2	Southeastern Purdue Agricultural Center, IN	8/5/2005	6.44	7.15	6.78	6.29	5.60	5.28		6.85	6.55	5.60	
Cincinnati Soil Sampling Point 3	Southeastern Purdue Agricultural Center, IN	8/5/2005	7.68	5.64	4.16	2.75	3.20			6.82	3.52	3.20	
Cincinnati Soil Sampling Point 4	Southeastern Purdue Agricultural Center, IN	8/5/2005	8.39	7.55	5.63	5.23	7.99			7.97	5.45	7.99	
Cincinnati Soil Sampling Point 5	Southeastern Purdue Agricultural Center, IN	8/5/2005	7.19	5.55	4.23	4.66	9.85			6.41	4.48	9.85	
Cobbsfork Soil Sampling Point 1	Southeastern Purdue Agricultural Center, IN	8/4/2005	5.68	7.25	2.81	2.24	2.84			6.59	2.53	2.84	
Cobbsfork Soil Sampling Point 2	Southeastern Purdue Agricultural Center, IN	8/4/2005	6.88	7.78	3.66	2.68	2.73			7.35	3.22	2.73	
Cobbsfork Soil Sampling Point 3	Southeastern Purdue Agricultural Center, IN	8/4/2005	6.94	8.54	2.96	2.87	2.83	6.47		7.78	2.92	2.83	
Cobbsfork Soil Sampling Point 4	Southeastern Purdue Agricultural Center, IN	8/4/2005	3.75	5.25	3.32	3.49	2.15			4.63	3.40	2.15	
Cobbsfork Soil Sampling Point 5	Southeastern Purdue Agricultural Center, IN	8/4/2005	6.01	8.96	5.58	2.68	2.42			7.84	4.47	2.42	
Parke Soil Sampling Point 1	Southeastern Purdue Agricultural Center, IN	8/4/2005	4.84	8.97	5.75	4.65	5.09			7.52	5.27	5.09	
Parke Soil Sampling Point 2	Southeastern Purdue Agricultural Center, IN	8/4/2005	5.13	6.01	3.41	3.41	3.91	2.43		5.62	3.41	3.91	
Parke Soil Sampling Point 3	Southeastern Purdue Agricultural Center, IN	8/4/2005	4.83	7.52	6.01	5.51	5.06	3.50		6.62	5.76	5.06	
Parke Soil Sampling Point 4	Southeastern Purdue Agricultural Center, IN	8/4/2005	4.12	7.43	4.94	4.55	4.60			6.26	4.76	4.60	
Parke Soil Sampling Point 5	Southeastern Purdue Agricultural Center, IN	8/4/2005	3.71	4.97	4.04	4.26	5.18			4.49	4.16	5.18	
Wilbur Soil Sampling Point 1	Southeastern Purdue Agricultural Center, IN	8/5/2005	8.05	10.60	8.07	4.50	4.87			9.52	6.88	4.87	
Wilbur Soil Sampling Point 2	Southeastern Purdue Agricultural Center, IN	8/5/2005	5.96	7.46	6.72	4.79	7.13			6.83	5.81	7.13	
Wilbur Soil Sampling Point 3	Southeastern Purdue Agricultural Center, IN	8/5/2005	5.54	7.33	4.08	4.06	6.98	5.63		6.54	4.07	6.98	
Wilbur Soil Sampling Point 4	Southeastern Purdue Agricultural Center, IN	8/5/2005	8.88	12.37	10.02	6.67	5.37			11.08	8.68	5.37	
Wilbur Soil Sampling Point 5	Southeastern Purdue Agricultural Center, IN	8/5/2005	8.23	8.80	5.86	6.20	5.08	4.21		8.54	6.04	4.97	

Table 7-7. Summary of average CBR values for SAS locations for fall IOP3.

Station	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
Cincinnati Soil Test pit (center)	10/31/2005	6.76	5.36	5.83	8.41	8.90	9.06		6.23	7.12	8.99	
Cincinnati Soil Sampling point 2 (east)	10/31/2005	5.64	6.55	6.45	6.66	7.51	8.33	3.65	6.15	6.55	7.75	3.65
Cincinnati Soil Sampling point 2 (north side)	10/31/2005	3.78	7.72	5.35	2.45	2.32	1.51		6.14	3.70	2.05	
Cincinnati Soil Sampling point 4 (west side)	10/31/2005	5.71	4.89	4.70	6.18	11.21	14.40		5.40	5.52	12.27	
Cincinnati Soil Sampling point 5 (south side)	10/31/2005	5.34	5.44	5.96	7.00	7.49	14.60		5.38	6.48	10.33	
Cobbsfork Soil Sampling Point 1 (near test pit location)	10/31/2005	4.09	6.87	5.52	13.82	6.14	5.19		5.48	10.50	5.60	
Cobbsfork Soil Sampling Point 2 (east side)	10/31/2005	3.61	7.89	3.30	2.54	3.06	5.36	6.47	6.10	2.92	4.37	6.47
Cobbsfork Soil Sampling Point 3 (north side)	10/31/2005	6.95	7.78	2.68	3.09	3.63	4.79		7.30	2.91	4.29	
Cobbsfork Soil Sampling Point 4 (west side)	10/31/2005	4.29	7.65	5.40	3.47	2.70	4.52	4.56	6.31	4.43	3.86	4.56
Cobbsfork Soil Sampling Point 5 (south side)	10/31/2005	7.27	10.82	2.95	4.94	4.72	5.81	5.63	8.88	4.18	5.34	5.63
Parke Soil Test pit (center)	10/31/2005	3.86	5.17	4.44	4.86	5.18	5.65	4.44	4.44	4.62	5.32	4.44

Table 7-7 (cont'd). Summary of average CBR values for SAS locations for fall IOP3.

Station	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
Parke Soil Sampling point 2 (east)	10/31/2005	3.81	4.39	3.55	4.01	5.09	6.36		4.10	3.78	5.43	
Parke Soil Sampling point 3 (north)	10/31/2005	4.77	5.26	4.19	5.16	5.95	8.56		5.01	4.68	6.99	
Parke Soil Sampling point 4 (west)	10/31/2005	5.38	7.63	5.23	4.30	4.09	4.17	10.19	6.61	4.69	4.12	10.19
Parke Soil Sampling point 5 (south)	10/31/2005	5.15	5.69	4.08	3.70	3.50	5.01		5.42	3.85	4.11	
Wilbur Soil Test point 1 (center)	10/31/2005	7.21	7.72	4.99	4.56	3.23	3.34	2.16	7.46	4.73	3.27	2.16
Wilbur Soil Sampling point 2 (east side)	10/31/2005	4.61	7.27	4.93	5.96	5.89	8.33		5.94	5.39	6.58	
Wilbur Soil Sampling point 3 (north side)	10/31/2005	3.15	5.75	5.78	5.24	7.10	10.40		4.78	5.48	8.75	
Wilbur Soil Sampling point 4 (west side)	10/31/2005	5.55	8.27	7.99	6.09	5.26	4.29	8.31	7.03	7.23	4.77	8.31
Wilbur Soil Sampling point 1 (south side)	10/31/2005	3.69	7.81	7.63	7.36	5.76	4.38		6.09	7.51	5.37	

Table 7-8. Summary of average CBR values for SAS locations for winter IOP4.

Station	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
Cincinnati Soil Sampling Point 1	3/2/2006	4.32	4.25	5.22	8.69	16.93	16.08		4.28	7.37	16.65	
Cincinnati Soil Sampling Point 2	3/2/2006	5.75	7.01	4.68	5.76	8.58	10.64		6.49	5.22	9.57	
Cincinnati Soil Sampling Point 3	3/2/2006	6.74	6.14	3.81	2.38	2.30	2.58		6.42	3.17	2.44	
Cincinnati Soil Sampling Point 4	3/2/2006	4.48	5.67	4.05	6.33	7.47	9.10		5.16	5.33	8.20	
Cincinnati Soil Sampling Point 5	3/2/2006	3.44	5.04	4.26	6.92	13.47	18.44		4.37	5.89	16.02	
Cobbsfork Soil Sampling Point 1	3/3/2006	4.95	6.66	2.95	2.71	3.96	5.42		6.02	2.84	4.69	
Cobbsfork Soil Sampling Point 2	3/3/2006	3.68	8.09	4.03	2.70	2.01	3.68		6.79	3.50	2.94	
Cobbsfork Soil Sampling Point 3	3/3/2006	5.62	10.00	3.40	3.97	4.21	5.88		8.20	3.68	5.10	
Cobbsfork Soil Sampling Point 4	3/3/2006	6.19	7.83	3.32	3.44	3.77	5.71		7.14	3.39	4.88	
Cobbsfork Soil Sampling Point 5	3/3/2006	3.67	9.94	2.77	1.36	3.06	4.45		8.29	2.30	3.75	
Parke Soil Sampling Point 2	3/2/2006	2.88	4.21	3.09	2.86	4.41	6.54		3.62	3.00	5.40	
Parke Soil Sampling Point 5	3/2/2006	3.89	4.09	4.15	4.63	6.08	9.71		4.00	4.39	7.90	
Wilbur Soil Sampling Point 1	3/2/2006	3.97	5.39	5.03	2.77	6.29	9.10		4.84	4.09	7.69	

Table 7-8 (cont'd). Summary of average CBR values for SAS locations for winter IOP4.

Station	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
Wilbur Soil Sampling Point 2	3/2/2006	6.36	6.61	4.00	4.46	7.65	9.11		6.49	4.23	8.35	
Wilbur Soil Sampling Point 3	3/2/2006	5.04	4.40	4.77	5.42	7.52	10.87		4.72	5.14	9.27	
Wilbur Soil Sampling Point 4	3/2/2006	13.10	9.69	7.33	6.33	5.89	4.75		11.19	6.88	5.40	
Wilbur Soil Sampling Point 5	3/2/2006	7.51	8.85	6.72	4.45	3.46	7.43		8.28	5.92	5.84	

Table 7-9. Summary of organic content testing for SAS locations.

Sample	Wet Wt	Tare	Dry Wt	Dry Soil	Water	Moisture Content		440C	% Ash	% Organic	Average
Cincinnati, April	187.27	131.81	176.27	44.46	11.00	24.74		174.45	98.97	1.03	
Cincinnati, August	116.51	67.71	115.30	47.59	1.21	2.54		112.42	97.50	2.50	
Cobbsfork, April	114.66	64.01	109.79	45.78	4.87	10.64		108.22	98.57	1.43	
Cobbsfork, April	141.71	82.95	136.29	53.34	5.42	10.16		134.59	98.75	1.25	
Cobbsfork, April	109.48	64.56	105.32	40.76	4.16	10.21		103.93	98.68	1.32	1.33
Cobbsfork, August	117.19	67.72	116.23	48.51	0.96	1.98		114.49	98.50	1.50	
Parke, April	124.65	67.72	118.76	51.04	5.89	11.54		116.49	98.09	1.91	
Parke, August	112.25	63.98	111.38	47.40	0.87	1.84		109.14	97.99	2.01	
Wilbur, April	126.91	67.71	115.75	48.04	11.16	23.23		113.59	98.13	1.87	
Wilbur, April	106.22	64.55	98.18	33.63	8.04	23.91		96.66	98.45	1.55	
Wilbur, April	142.07	76.41	129.97	53.56	12.10	22.59		127.68	98.24	1.76	1.73
Wilbur, August	173.31	131.80	172.46	40.66	0.85	2.09		170.81	99.04	0.96	

Soil organic content

The surface soil samples collected from the soil pit locations during the spring IOP were tested for organic content. The results of the organic contents for the SAS are in Table 7-9. The “Average” column provides the average for only the repeat samples. Because the soil types are different, no overall average value for all of the soils was calculated. Variability between repeat samples was 2%–10% for the Cobbsfork soil, and 4%–13% for the Wilbur soil.

7.3 Discussion of SAS soils

This section discusses the results of the field measurements collected during all IOPs, centering around the soil type, soil density, trends in moisture distribution, and soil strength. Changes to the condition of the soil surface may be considered insignificant since the test areas were maintained.

Although the visual color of the soils vary from light (Cobbsfork) to dark (Wilbur, Cincinnati, and Parke), the grain size analysis (Figs. 7-4–7-7) of the soil samples collected from the soil pits clearly shows the similarity. All four of the soils consist of fine-grained material with some plasticity characteristics. For the Cincinnati, Cobbsfork, and Wilbur soils, the USCS classification was CL throughout. The upper 150 mm (6 in.) of the Parke soil was classified as ML overlying CL down to a depth of 600 mm (24 in.). Therefore, the soils of all four of the SAS locations were classified the same types as the soils from the RASs.

The volumetric soil moisture measurements (Fig. 7-14, a–d) taken during each IOP show a trend where the highest moisture content throughout the soil profile occurs during the springtime, whereas the lowest moisture values occurred during the summer IOP. Both the fall and winter time periods fell between the wettest and driest times of the year, and they had similar moisture content values.

Based on the DCP measurements for the soil strength (Fig. 7-15, a–d), a trend emerges consistently showing the summer with the higher soil strength values, fall and winter in the middle, and spring with the lowest strength values. For the four soils, the soil strength is considered weak, with a CBR consistently less than 10 in the upper 150–450 mm (6–18 in.) layer. Using the soil surface strength requirements table for the C-130 aircraft, a minimum surface strength of approximately 1.6 CBR is needed to

support an aircraft gross load of 50,000 lbs resulting in 10 passes. Should this evaluation be valid, the Wilbur soil during both the summer and winter would scarcely meet this requirement. The Cincinnati and Parke soils might only meet this requirement during the winter. The Cobbsfork soil shows a slightly greater surface soil strength during both the summer and winter IOPs, although for the summer IOP a minimum of 1.6 CBR was recorded at the center test point (soil pit location). However, the surface strength varies. Given that the soil density also shows variability, it is difficult to say that the soil would indeed be capable of supporting any aircraft operations with certainty

8 Conclusions

The three goals of the ERDC OLS program were: (1) to evaluate the ability of the OLS-MS software to locate smooth, flat, level, and obstruction-free areas for landing zones using multispectral Landsat imagery; (2) to evaluate the ability of the OLS-MS software to locate OLSs in any season; and (3) to evaluate the OLS-MS software for its ability to locate landing zones with a bearing capacity capable of supporting aircraft operations. The field work conducted in southeastern Indiana at the North Vernon Airport and Ford Farm RAS locations, as well as the four SAS locations, provided a means to quantify, via "ground truth" measurements, important features of the OLSs to assess the capability of the OLS-MS software.

The ability of the OLS-MS software to locate smooth, flat, level, and obstruction-free landing zone areas was carried out using a Landsat 5 image from March 17, 2005, path 20, row 33, with the Boeing OLS-MS software Version 7. The software identified numerous OLSs, the majority of which were briefly evaluated during an initial site visit. A number of the OLSs identified by the software intersected obstructions, such as drainage ditches, roads, and utility lines that were not recognized by the software. The two OLSs selected for detailed assessment met the evaluation criteria for smooth and level when compared with existing dimensional criteria.

Although the overall OLS may meet the dimensional criteria for smoothness, flatness, etc., assessing the terrain surface at a smaller scale shows serious deficiencies that could affect aircraft operations. In particular, the wide drainage areas greater than 6-in. deep would require mitigation.

The effect of seasonal change did affect the number of OLSs identified, with the largest number of OLSs occurring during the winter season. Different versions of the software, Versions 7 and 10, illustrated the uniqueness of each Landsat image and the locations of OLSs. However, it is unclear why previously identified OLSs were not located when the software run was repeated on the same Landsat image.

Ground truth measurements consisted of visual observations of the surface conditions encountered each season and measurements to determine the physical properties of the areas of interest. The techniques used to

evaluate the RAS locations provide a methodology to assess potential OLSs. Soil samples were collected and measurements were made of the soil moisture, soil density, and soil strength. All of these measurements were taken with depth, down to a minimum of 0.6 m (2 ft) below the soil surface.

The soils at the North Vernon Airport and Ford Farm RASs were classified as a lean clay with sand. The same soil type was also identified at all four of the SAS locations. This soil type is fine-grained and has some plasticity, meaning that it will deform under loading conditions. The soil type was consistent through the sampling depth. The density of the soils is low and varies somewhat with depth because of the presence of voids from animal holes, as well as the general lack of confinement of the soils, most likely due to agricultural activities where some air entrainment in the soil is desirable for growing crops.

The moisture measurements collected each season reveal that the soils are poorly draining and moisture is retained throughout the season. This combined with a high water table, particularly at the North Vernon Airport RAS, results in a weaker soil matrix. Three of the four seasons had high moisture content readings. Similar moisture readings were also found at the Ford Farm RAS.

The soil measurements collected from the four SAS locations were consistent with the measurements made at the RAS locations. The soil types were also similar to those at the RAS locations, and the soil strength measurements displayed comparable trends as the RAS locations.

Soil strength measurements taken with the DCP showed soil strength that varied considerably along the RAS. The overall soil strength was low for both RAS locations. The measurement of the upper soil strength was more difficult. Although the portability and simplicity of the lightweight Clegg hammer was useful, the resulting measurements did not correspond well to measurements made with either the DCP or the cone penetrometer. The Clegg hammer consistently underpredicted the strength of the soil surface.

Based on the evaluation completed at the two RAS locations, only the soil strength measurements from the Ford Farm RAS during the summer IOP2 showed adequate strength to support several aircraft passes. However, the dense vegetation coverage from the corn crop may hinder operations. The

remaining soil strengths from the IOPs did not provide adequate bearing capacity consistently along the RAS.

References

Affleck, R. T., C. Ryerson, L. Barna, and K. Claffey (2008a) *Opportune landing site (OLS) program: suitability measurement and analysis for El Centro Naval Air Facility OLS*. ERDC/CRREL Technical Report TR-08-18. Hanover, NH: U.S. Army Engineer Research and Development Center.

Affleck, R. T., C. Ryerson, L. Barna, and K. Claffey (2008b) *Opportune landing site (OLS) program: suitability measurement and analysis for Fort Bliss OLS*. ERDC/CRREL Technical Report TR-08-16. Hanover, NH: U.S. Army Engineer Research and Development Center.

Air Force (2002) *Airfield pavement evaluation standards and procedures*. AFCESA/CES Engineering Technical Letter 02-19. Tyndall Air Force Base, FL: Air Force Civil Engineer Support Agency.

Air Force (2004) *C-130 and C-17 landing zone (LZ) dimensional, marking, and lighting criteria*. AFCESA/CES Engineering Technical Letter 04-07. Tyndall Air Force Base, FL: Air Force Civil Engineer Support Agency.

Almassy, R., and P. Blake (2005) *Opportune landing site multispectral (OLS-MS) software operation description, version 7.0*. Chicago, IL: Boeing Company,

Almassy, R., and P. Blake (2007) *Opportune landing site multispectral (OLS-MS) software operation description, version 10.0*. Chicago, IL: Boeing Company.

Alvin, D.W. (2000) *Paradigm lost, rethinking theater airlift to support the army after next*. CADRE Paper No. 9. Maxwell AFB, AL: Air University Press.

ASTM (1963) D 422 *Standard test method for particle-size analysis of soils*. West Conshohocken, PA: ASTM International.

ASTM (1971) D 2974 *Standard test methods for moisture, ash, and organic matter of peat and other organic soils*. West Conshohocken, PA: ASTM International.

ASTM (1985) D 421 *Standard practices for dry preparation of soil samples for particle-size analysis and determination of soil constants*. West Conshohocken, PA: ASTM International.

ASTM (1995) D 4220 *Standard practices for preserving and transporting soil samples*. West Conshohocken, PA: ASTM International.

ASTM (1998) D 2216 *Standard test method for laboratory determination of water (moisture) content of soil and rock by mass*. West Conshohocken, PA: ASTM International.

ASTM (2004a) D 2922 *Standard test methods for density of soil and soil-aggregate in place by nuclear methods (shallow depth)*. West Conshohocken, PA: ASTM International.

ASTM (2004b) D 2937 *Standard test method for density of soil in place by the drive-cylinder method*. West Conshohocken, PA: ASTM International.

ASTM (2004c) D 3017 *Standard test method for water content of soil and rock in place by nuclear methods (shallow depth)*. West Conshohocken, PA: ASTM International.

ASTM (2005) D 4318 *Standard test methods for liquid limit, plastic limit, and plasticity index of soils*. West Conshohocken, PA: ASTM International.

ASTM (2006) D 2487 *Standard practice for classification of soils for engineering purposes (unified soil classification system)*. West Conshohocken, PA: ASTM International.

Coleman, D. M. (1988) Variability in field density test methods used for quality control. MS thesis, Department of Civil Engineering, Mississippi State University.

Delta-T Devices (1999) *ThetaProbe soil moisture sensor Type ML2x user manual, ML2x-UM-1.21*. Cambridge, UK: Delta-T Devices Ltd.

Department of the Army (1985) *Pavement design for seasonal frost conditions*. Technical Manual 5-818-2. Washington, DC: Headquarters, Departments of the Army and the Air Force.

HQ Army and Air Force (1994) *Planning and design of roads, airfields, and heliports in the theater of operations—road design*. FM 5-430-00-1/AFJPAM 32-8013, Vol. 1. Washington DC: Headquarters, Departments of the Army and Air Force.

Department of the Defense (2006) *Quadrennial defense review report*. Washington DC: Secretary of Defense, Department of Defense. Available at: http://www.globalsecurity.org/military/library/policy/dod/qdr-2006-report.htm.

Grant, S. (2006) Personal communication. December 2006.

Haren, R. (2005) Personal communication, 2005. Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio

McMichael, S. R. (2007) *Mounted vertical maneuver: a giant leap forward in maneuver and sustainment*. Military Review. Fort Leavenworth, KS: U.S. Headquarters, Department of the Army, Army Combined Arms Center. http://militaryreview.army.mil.

Myers. R. (2006) Personal communication, November 15, 2006. Research Triangle Park, NC: Troxler Electronic Laboratories, Inc.

Nickell, A. K. (1976) *Soil survey of Jennings County, Indiana*. Washington, DC: Soil Conservation Service, U.S. Department of Agriculture.

Nickell, A. K. (1985) *Soil survey of Jefferson County, Indiana*. Washington, DC: Soil Conservation Service, U.S. Department of Agriculture, in cooperation with Purdue University Agricultural Experiment Station and Indiana Department of Natural Resources, Soil and Water Conservation Committee.

Reynolds, M. (2007). Personal communication. January 11, 2007.

Rollings, M. P. and R. S. Rollings, Jr. (1996) *Geotechnical materials in construction*. New York: McGraw-Hill.

Rollings, R. S. Jr. (2006) Personal communication. Rollings Consulting, LLC. Beaufort, SC. November 14, 2006.

Ryerson, C., and J. McDowell (2007) Anywhere-anytime: enhancing battlespace vertical mobility. In *AIAA 2007-1103, American Institute of Aeronautics and Astronautics 45th Aerospace Sciences Meeting and Exhibit, 8-11 January, Reno, NV*. Reston, VA: American Institute of Aeronautics and Astronautics.

Scott, Forrest R., Lynette A. Barna, Rosa T. Affleck, Keran J. Claffey, Elke S. Ochs, and Charles C. Ryerson (in press) *OLS program: field data archive*. ERDC/CRREL Technical Report. Hanover, NH: U.S. Army Engineer Research and Development Center.

SDi (2000) *Clegg impact soil tester, operators manual*. Trowbridge, Wiltshire, UK: Simon Deakin Instrumentation.

Shoop, S. A., D. Diemand, W. L. Wieder, G. Mason, and P. M. Seman (2008) *Predicting California bearing ratio from trafficability cone index values*. ERDC/CRREL Technical Report. TR-08-17. Hanover, NH: U.S. Army Engineer Research and Development Center.

Troxler (2003) *Model 3440 surface moisture-density gauge, manual of operation and instruction*. Research Triangle Park, NC: Troxler Electronic Laboratories, Inc. http://www.troxlerlabs.com.

USGS Digital Orthophotos (2007) Washington, DC: U.S. Geological Survey. http://online.wr.usgs.gov/ngpo/doq/doq_basics.html. Accessed: 2007.

Vincent, R.K., and D.L. Jennings (2004) A four-state evaluation of the Boeing landing suitability index (BLSI) for automatically mapping candidate aircraft operating sites in natural terrain from LANDSAT TM Data. *Journal of Terramechanics* 41:151–162.

Appendix A: Initial Field Visit to Southeastern Indiana

This report has been included for informational purposes only. Personal information has been removed.

CEERD-RS Trip Report April 5, 2006

Subject

Trip Report: Southeastern Indiana OLS Logistics Meeting Potential Field Site Inspection, April 4–7, 2005.

Objectives

Inspect OLSs selected by Boeing software in southeastern Indiana using March 17, 2005 LANDSAT 5 imagery, select OLSs for field study, and arrange logistics.

Subjects discussed

- McDowell, Barna, and Ryerson spent two days in the field visiting OLS locations in southeastern Indiana around and near Jefferson Proving Ground and the Southeast Purdue Agricultural Center (SEPAC), mapped by the Boeing software Version 7 dated March 27, 2005, using LANDSAT 5 frame 020_033 for March 17, 2005. The software was run with a flatness index of 0.02, and a vegetation index of 1.8 (yellow), 1.7 (red), and 1.6 (blue). OLSs were plotted over an orthophotoquad to provide landmarks. A list of OLSs was created that included OLS number, end-point coordinates in UTM, direction, and length.
- Following are discussions of OLSs located by the Boeing software and located in southeastern Indiana using a GPS with the Wide Area Augmentation System. Landowners also assisted with locating OLSs. Figure 1 shows 16 areas of OLS groupings mapped. Runways are overlaid on 5-m resolution orthophoto imagery from the late 1990s. OLSs are referred to by their area number and the OLS number in the following descriptions. Green arrows denote approximate viewing positions when viewed on the ground. No OLS was inspected in its entirety to allow time to visit more sites. Most OLSs in Areas 1–11 were inspected,

with very general inspections, as were Areas 12, 13, and 16. No inspections occurred in Areas 14 and 15.

1. The first site inspected was a large cluster of OLSs in Area 2 directly across from North Vernon Municipal Airport (Figs. 2–5). The field, containing perhaps 50 OLSs, appeared quite flat, smooth, and, except for drainage ditches, obstruction free. However, the field was wet and soft. In addition, a ditch approximately 1-m deep and 3-m across crossed most of the north-south oriented OLSs. At the time, the airport was installing an AWOS weather station that would be available for data acquisition (Fig. 6).
2. OLS 3111 in Area 5 (Fig. 7) crossed a field from east to west. The field was smooth, flat, and apparently free of obstructions, although we did find that ditches were difficult to locate from a distance. Figure 8 shows water standing in the field, although perhaps not in the OLS.
3. OLS 229 in Area 10 (Figs. 9–12) was inspected near the middle of its length where it crossed a paved road with perimeter ditches and a power line. Fields on either side of the road were flat and smooth (except for tillage and tractor tire furrows), but wet and soft. The ditch on either side of the road was about 0.3-m deep.
4. OLS 292 in Area 10 (Figs. 13–17). Although flat to the eye and smooth except for corrugations due to normal tilling and tractor tires, OLS 292 crossed a paved road. Soil on the OLS was very wet and soft, with standing water in some tractor tire ruts. A single pole line runs along the road edge, and ditches parallel the road sides. The pavement is asphalt and is nearly two vehicle widths wide. The road is visible as a lighter tone in the LANDSAT image used to locate the OLS (Fig. 18).
5. OLSs 335, 1429, 1430, 2099, and 3095 Area 10 (Figs. 19–21) all cross corn fields. These fields were not walked. However, they appear flat and free of obstruction. Both fields had been cropped with corn the previous year and exhibited the typical corn stubble and tillage and farm implement rutting. Both fields were wet, although little standing water was observed.
6. Area 5 includes a field with a large cluster of OLSs, both yellow and red, indicating that most (yellow) were selected with the less strict greenness index of 1.8, and several were selected with a more strict greenness index of 1.7 (red) (Fig. 22). The field appears to be level, smooth, and flat; it appears to have been cultivated the previous year in soybeans, leaving less agricultural debris on the surface than found in cornfields (Figs. 23 and 24). Several OLSs are oriented east-west and, thus, appear to be free of obstructions. However, the majority of OLSs are oriented either north-south or northwest to southeast. It appears that all of these north-south trending

OLSs cross a single-lane dirt road paralleled by a single-pole power line near their center (Fig. 25).

7. Area 4 contains a cluster of OLSs that vary considerably in quality, having no obstructions, but also crossing roads and drainage ditches (Fig. 26). OLS 115 is within a corn field and parallels a road. However, the OLS crosses land that is quite hilly and, most significantly, crosses a major drainage ditch (Figs. 27–29). The drainage ditch is approximately 10- to 15-m wide and several meters deep (Fig. 28). Several OLSs in this area appear to have no obstructions or significant elevation changes, such as numbers 2095, 2096, and 3094 (Figs. 30 and 31). However, OLS 131 and 1412 cross a road (Fig. 30). Figures 33 and 34 show where these two OLSs cross the road. Although the fields on either side may be satisfactory, except perhaps for soil strength, the road drainage ditches, pavement, and pole line might cause difficulties.
8. Area 7 contains three clusters of OLSs. The cluster that contains OLSs 1373, 1375, 3663, 2557, and others was inspected because it was close to a road and could be readily evaluated (Fig. 35). Figure 36 shows the location of this cluster, which is on smooth, flat land. Notably, the OLSs are oriented such as to miss the barn in Figure 36—a notable achievement.
9. Figure 37 shows two OLSs on the western side of Area 6 encompassing OLSs 1458 and 1459. Figure 38 shows a ground view. These OLSs were chosen for later field work. The software located the OLSs, avoiding hills, valleys, and other obstacles.
10. OLSs 460 and 461 are in Area 12, situated on gently rolling land (Figs. 39 and 40). The OLSs cross a road (Fig. 40).
11. OLSs 819, 4091, 3636, 3051, 3052, and 3053 are located in the southern end of Area 16 (Figs. 1 and 41). OLS 3053 crosses a road, whereas all of the other OLSs appear not to cross obstructions. Figures 42–44 show the two ends of OLS 3053 and the area where the road is crossed. Except for the road crossing, OLS 3053 appears to be flat and free of obstructions.
12. Figure 45 shows additional OLS clusters in Area 16 (Fig. 1). Figure 46 shows the fields where many of these OLSs are located—largely flat and free of obstructions except for some standing water. However, Figure 47 shows where OLS 831 crosses a road with a relatively deep drainage ditch on one side and a paralleling single-pole power line.

13. Figure 48 shows a cluster of OLSs in the northern portion of Area 16 (Fig. 1). Figures 49 and 50 show where most of the OLSs are located north and south of the road that crosses through the western end of the cluster. These many OLSs appear to cover flat fields with no obstructions.
14. Figures 51–53 show OLSs located on the eastern side of Figure 48—primarily east of the north-south road. The landscape is largely flat and free of obstructions. However, some east-west trending OLSs appear to cross the north-south road beyond the stop sign in Figure 51, and are also visible in Figure 53.

Assessment

Although the OLS software successfully located many OLSs in relatively smooth, flat, and obstruction-free locations, it also failed at many locations. Most failures were due to road crossings, often accompanied by single-pole power lines. However, several crossings of drainage ditches also occurred. In some locations, the software was notably successful; an example is where two OLSs (1458 and 1459) were placed between hills, valleys, and trees at the only potential OLS location for several miles around. Two OLSs were selected as runway analysis sites (RAS) as a result of this survey and coordination with landowners. These two sites are OLSs 1458 and 1459, and the OLS number located across from North Vernon Municipal Airport. We arranged to place soil moisture and soil temperature sensors at the airport AWOS site, a weather station at the Ford Farm site. We also arranged to work at four soil analysis sites (SAS) at SEPAC and the Muscatatuck Urban Training Center operated by the Indiana National Guard.

Action items

- Make formal arrangements with RAS and SAS landowners.
- Provide software performance feedback to Boeing.

Report Figures 1—53

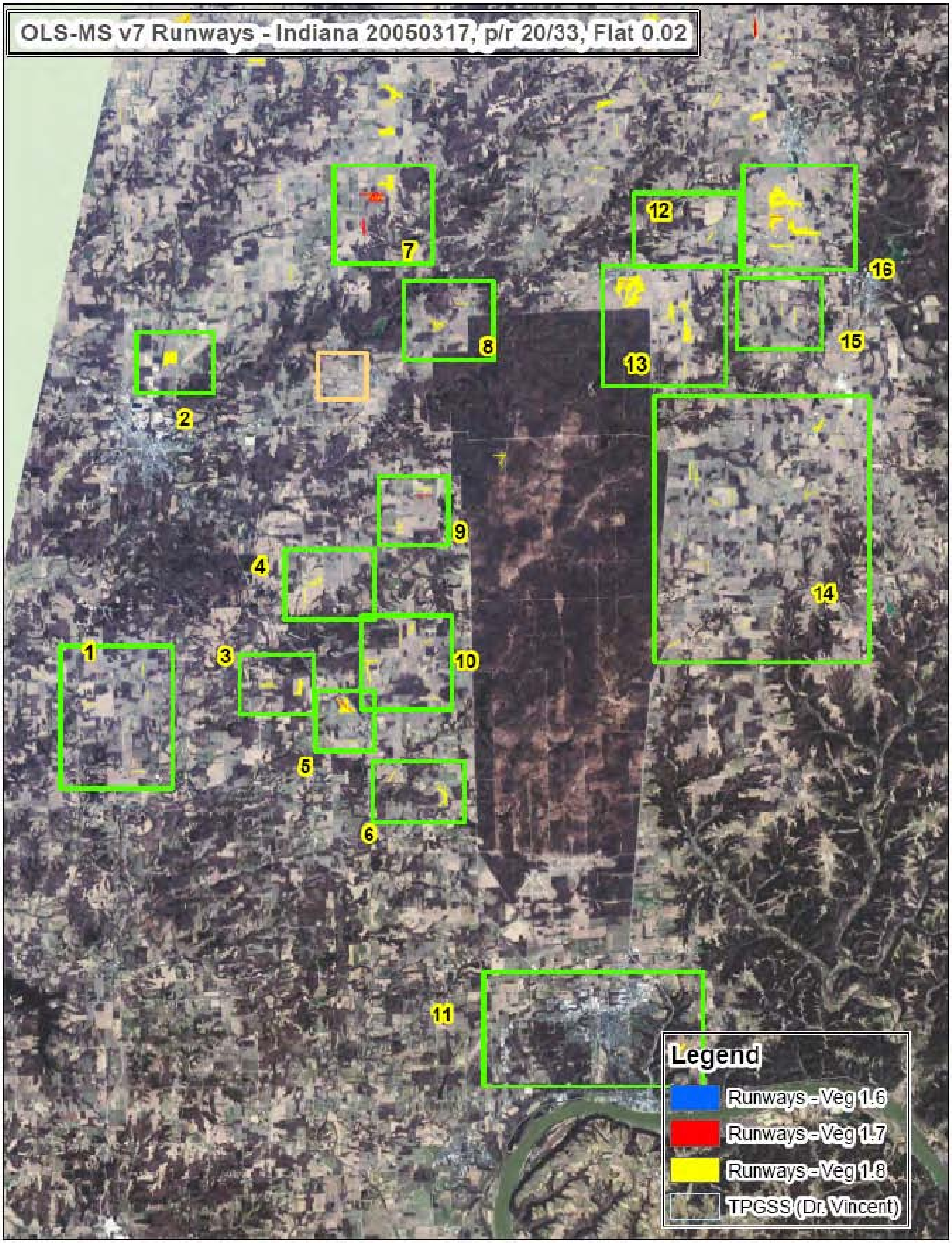

OLS-MS v7 Runways - Indiana 20050317, p/r 20/33, Flat 0.02
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Legend
Runways - Veg 1.6
Runways - Veg 1.7
Runways - Veg 1.8
TPGSS (Dr. Vincent)

Figure 1.

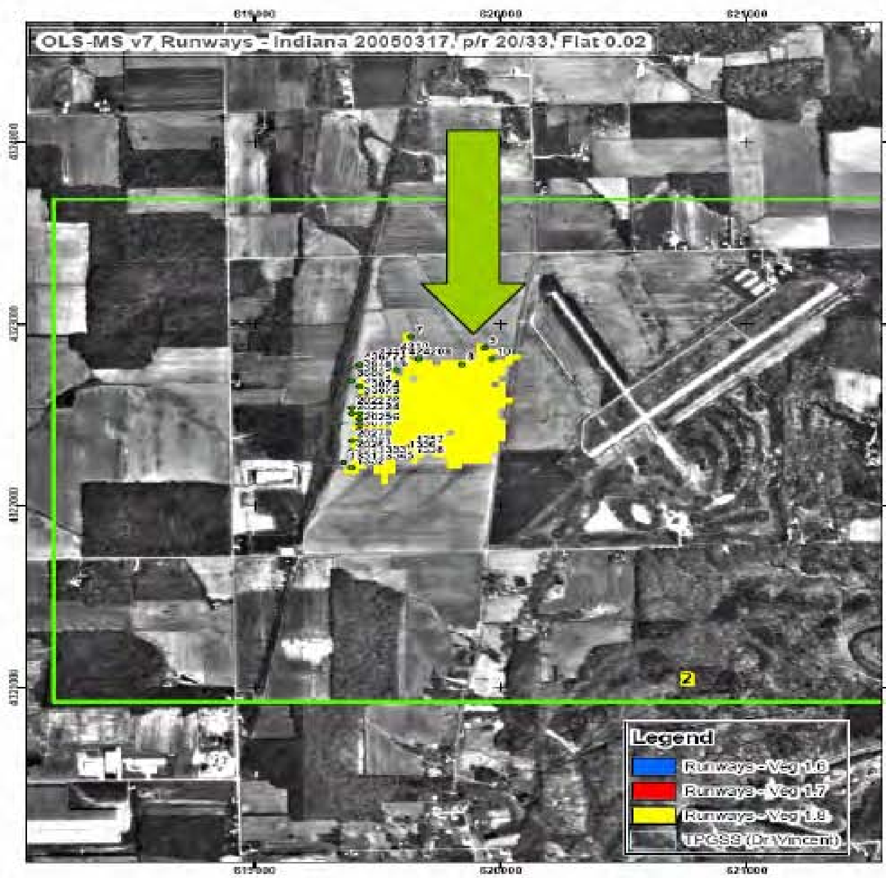


Figure 2.

Figure 3.

Figure 4.

Figure 5.

Figure 6.

Figure 7.

Figure 8.

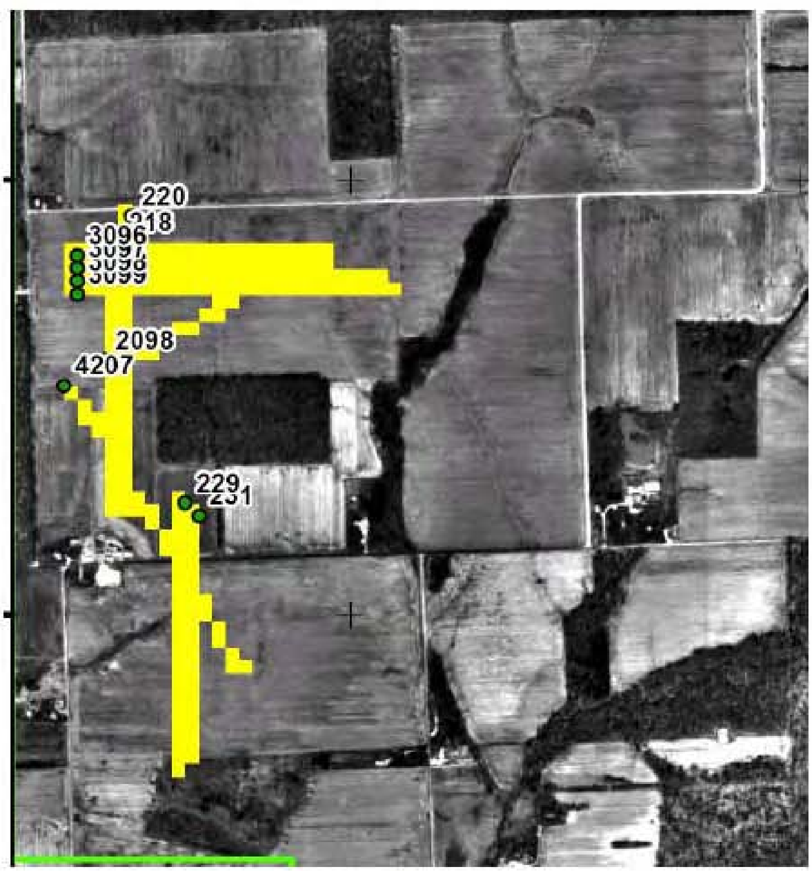


Figure 9.

Figure 10.

Figure 11.

Figure 12.

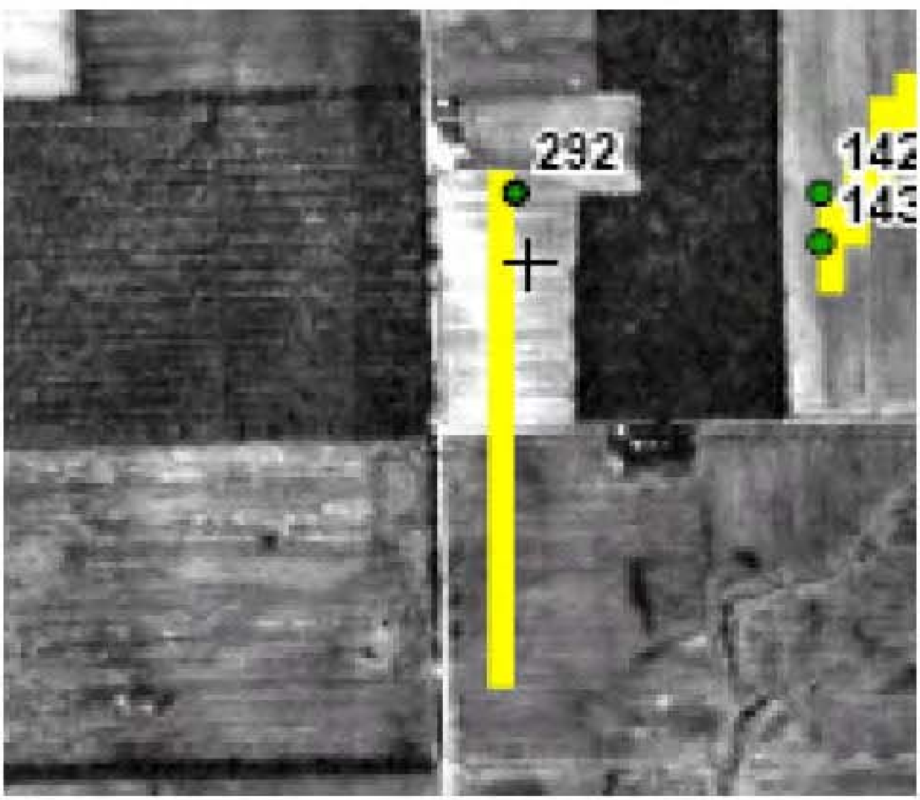


Figure 13.

Figure 14.

Figure 15.

Figure 16.

Figure 17.

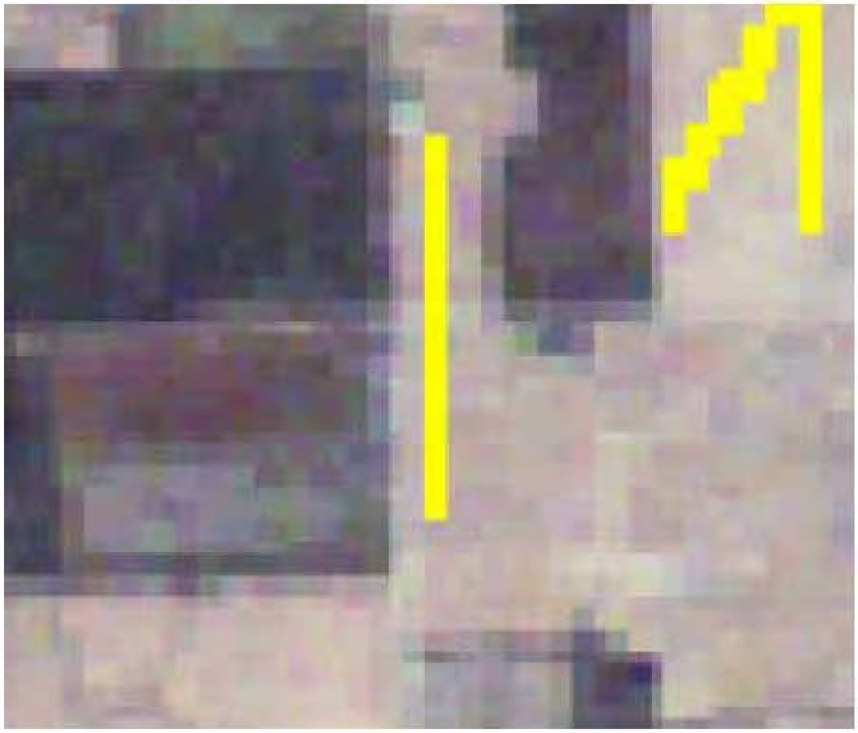


Figure 18.

Figure 19.

Figure 20.

Figure 21.

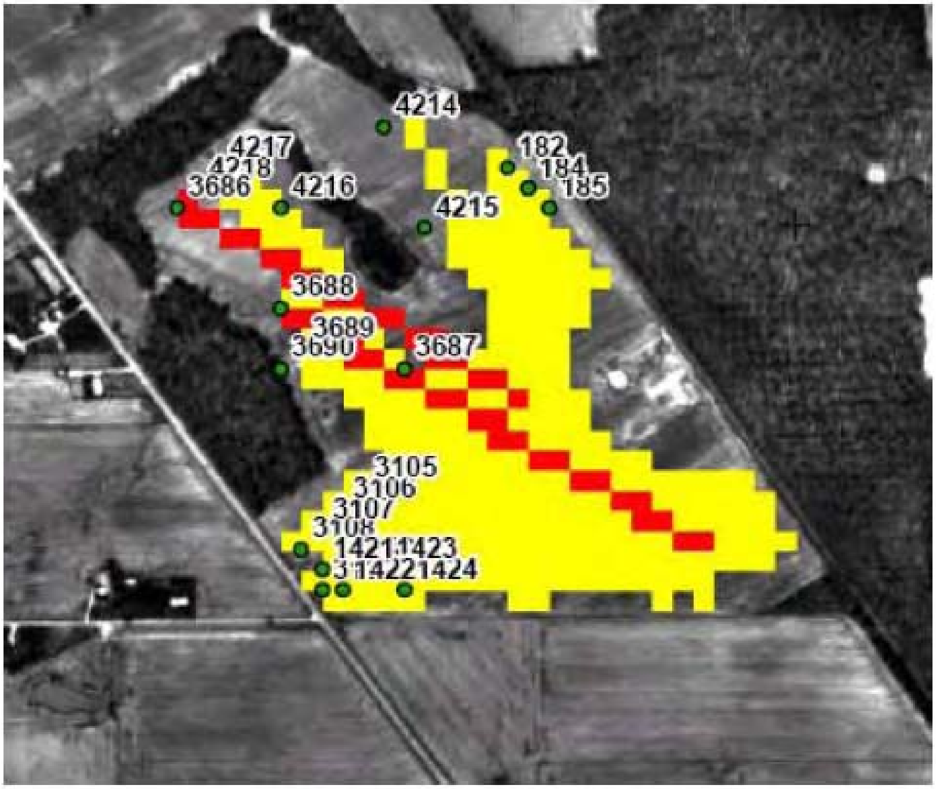


Figure 22.

Figure 23.

Figure 24.

Figure 25.

Figure 26.

Figure 27.

Figure 28.

Figure 29.

Figure 30.

Figure 31.

Figure 32.

Figure 33.

Figure 34.

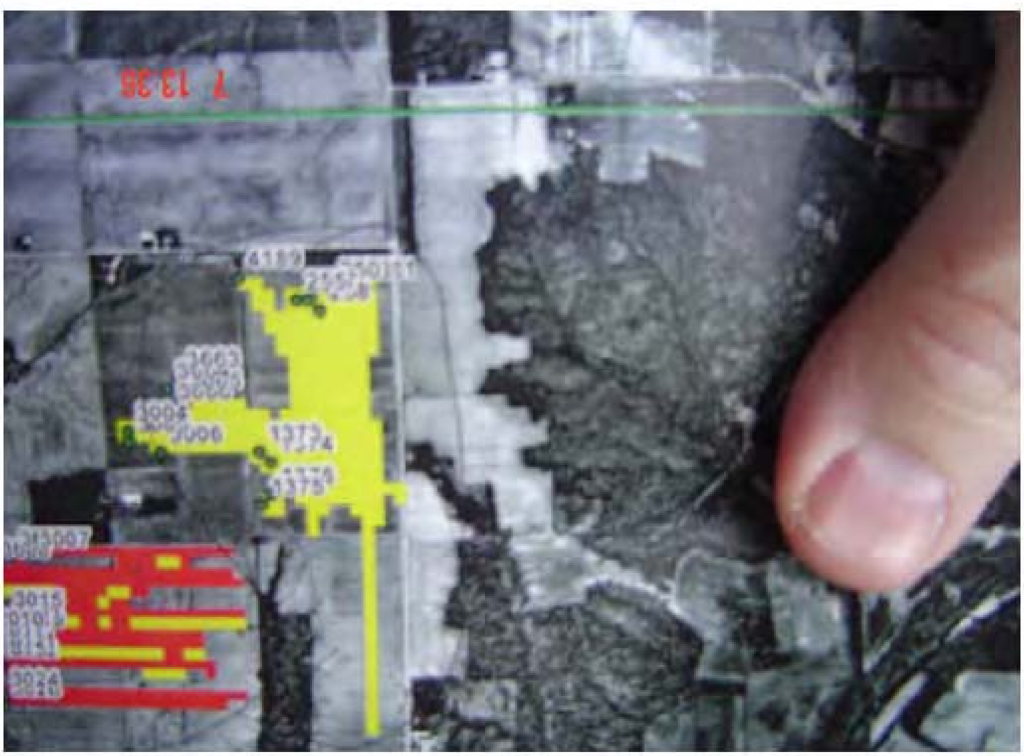


Figure 35.

Figure 36.

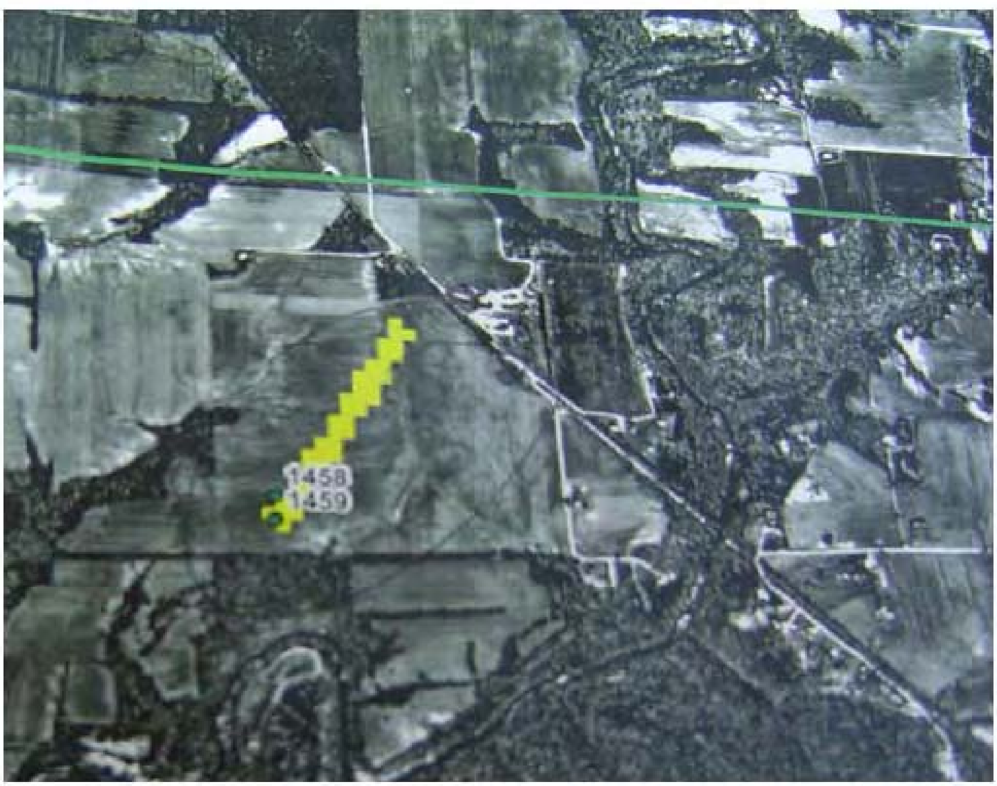


Figure 37.

Figure 38.

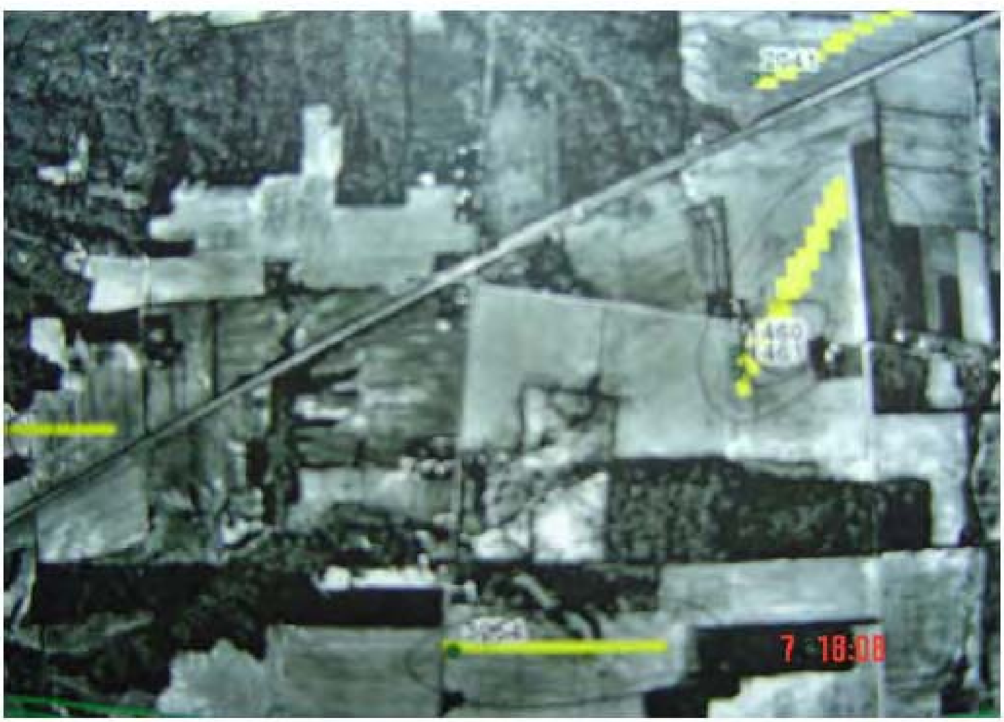


Figure 39.

Figure 40.

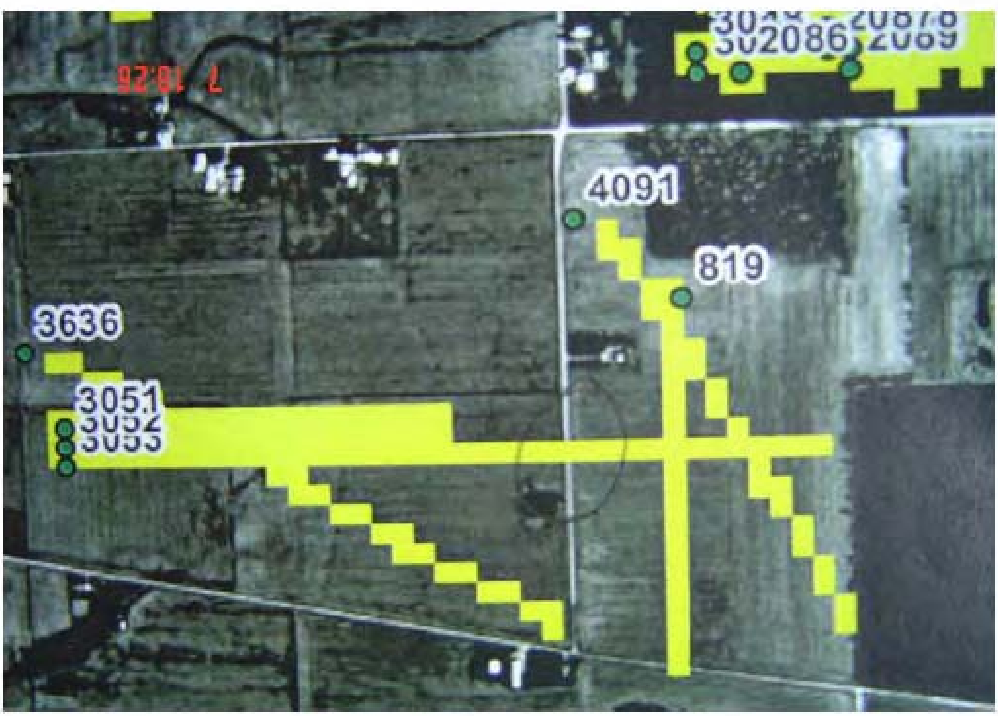


Figure 41.

Figure 42.

Figure 43.

Figure 44.

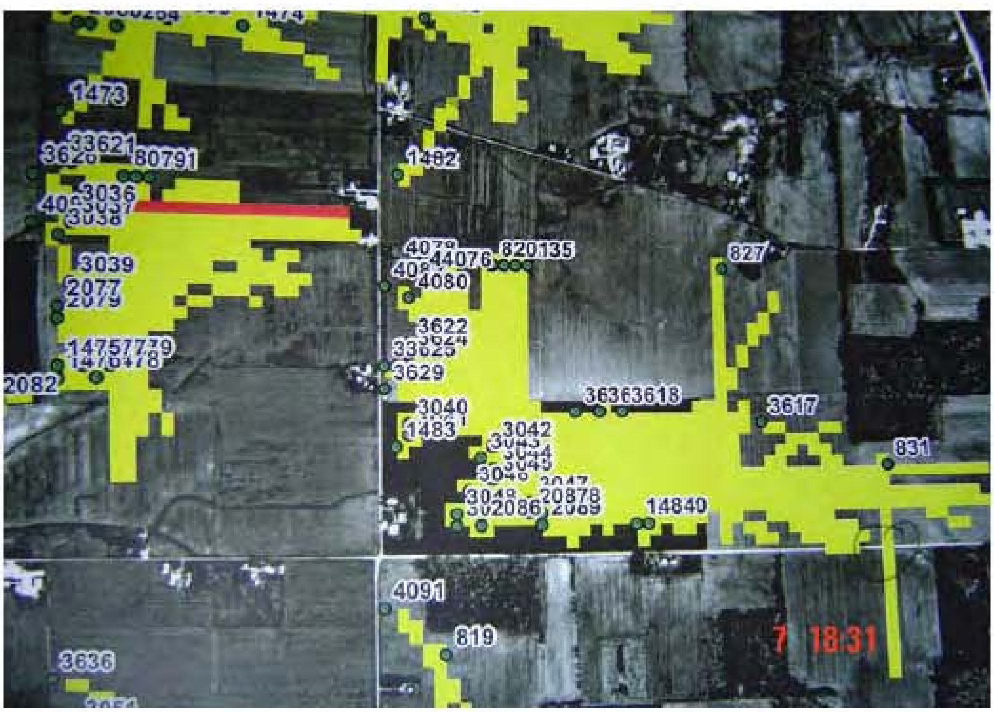


Figure 45.

Figure 46.

Figure 47.

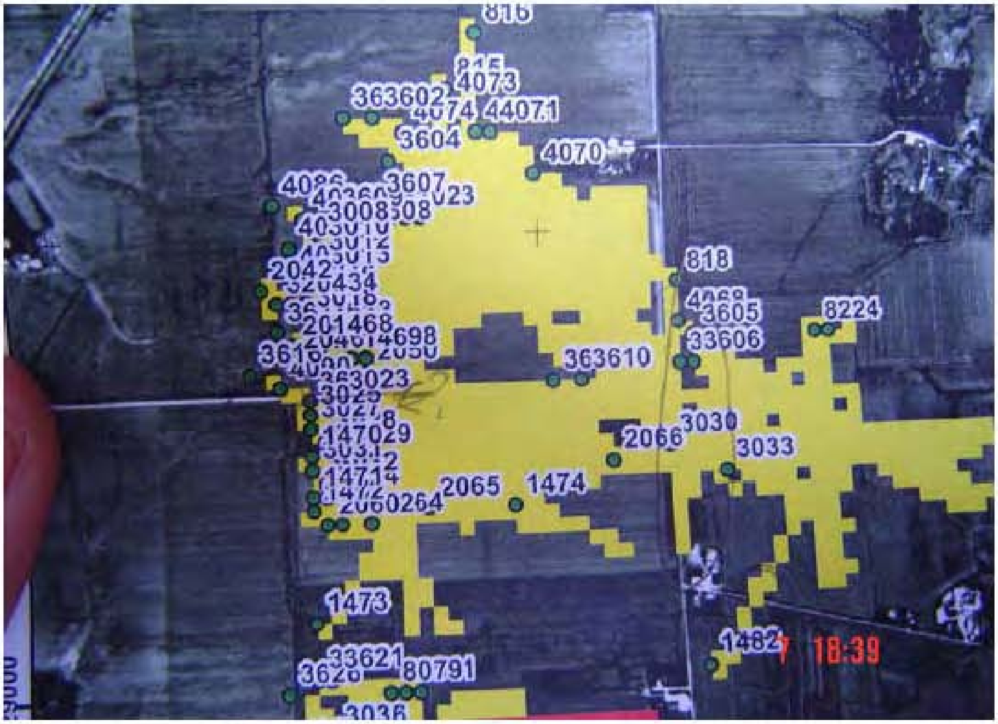


Figure 48.

Figure 49.

Figure 50.

Figure 51.

Figure 52.

Figure 53.

Appendix B: North Vernon Airport RAS Data

Table B-1. Soil field measurements taken at North Vernon Municipal Airport sampling points during each season.

	SPRING 2005								SUMMER 2005								FALL 2005								WINTER 2006							
Sampling points	DCP[1]	Clegg[2]	Army Cone[3]	Dor Cone[4]	Dynamax[5]	S[6]	D[7]	V[8]	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V
0m 10mN									x[9]	x			x				x	x			x				x	x	x		x			
0m 10mS									x	x			x				x	x			x				x	x	x		x			
0m CL	x		x						x	x			x				x	x	x		x				x	x	x		x			x
15m CL			x						x	x			x				x	x	x		x				x	x	x		x			x
60m 2mN	x																															
60m CL			x						x	x			x				x	x	x		x				x	x	x		x			x
120m 10mN	x								x	x			x				x	x			x											
120m 10mS	x								x	x							x	x			x											
120m 2mN			x		x	x	x	x														x	x									
120m 2mS			x																													
120m CL	x		x						x	x			x				x	x	x		x				x	x	x		x			x
150m 10mN									x	x			x				x	x			x											
150m 10mS									x	x			x				x	x			x											
150m CL			x						x	x			x				x	x			x											
180m 2mN	x		x																													
180m 2mS			x		x	x	x	x														x	x									
180m CL			x						x	x			x				x	x	x		x				x	x	x		x			x
240m 2mN	x		x		x	x	x	x																								
240m 2mS	x																															
240m CL			x						x	x			x				x	x	x		x				x	x	x		x			x
300m 10mN									x	x			x				x	x			x				x	x	x		x			
300m 10mS									x	x			x				x	x			x				x	x	x		x			
300m CL	x		x		x	x	x	x	x	x			x				x	x	x		x	x	x		x	x	x		x			x
360m 2mN	x		x																													
360m 2mS			x																													
360m CL			x						x	x			x				x	x	x		x				x	x	x		x			x
420m 10mN																	x															
420m 2mS	x																															
420m CL			x						x	x			x				x	x	x		x				x	x	x		x			x
450m 10mN									x	x			x				x	x			x											
450m 10mS									x	x			x				x	x			x											
450m CL																	x	x			x											
480m 10mN	x								x	x							x	x			x											
480m 10mS	x								x	x							x	x			x											
480m 2mN			x																													
480m 2mS			x		x	x	x	x														x	x									
480m CL	x		x						x	x			x	x			x	x	x		x				x	x	x		x			x
540m 2mN			x																													
540m 2mS	x		x																													
540m CL			x						x	x			x	x			x	x	x		x				x	x	x		x			x
585m CL			x						x	x			x				x	x	x		x				x	x	x		x			x
600m 10mN									x	x			x				x	x			x				x	x	x		x			
600m 10mS									x	x			x				x	x			x				x	x	x		x			
600m CL	x		x						x	x			x				x	x			x				x	x	x		x			x
Weather Station																	x	x			x	x										

[1] DCP = Dynamic Cone Penetrometer (Strength Profile)
[2] Clegg = Clegg Hammer (Surface Strength)
[3] Army Cone = Cone Index (Strength Profile)
[4] Dor Cone (Surface Strength)
[5] Dynamax = Soil Moisture (Surface and/or with depth)
[6] S = Soil sample(s) taken
[7] D = Density (Density using Troxler and/or Density using drive cylinder)
[8] V = Vegetation Cover (images)
[9] x indicates that a measurement was taken

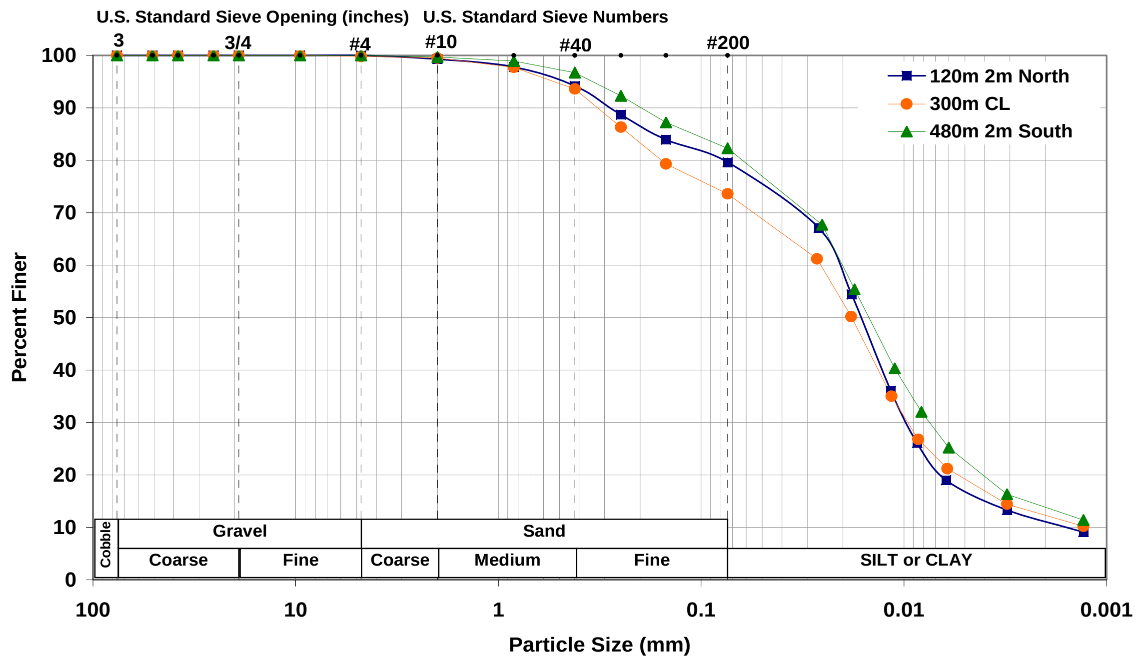


Figure B-1. Gradation analysis for 25- to 152-mm (1- to 6-in.) soil samples.

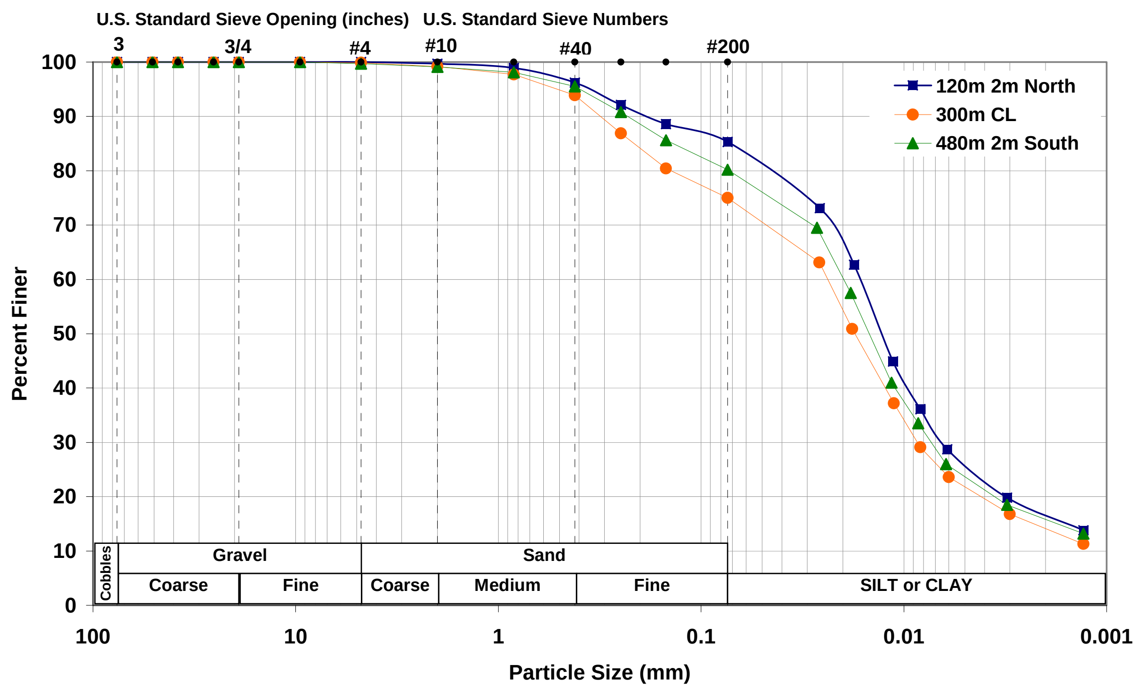


Figure B-2. Gradation analysis for 300-mm (12-in.) soil samples.

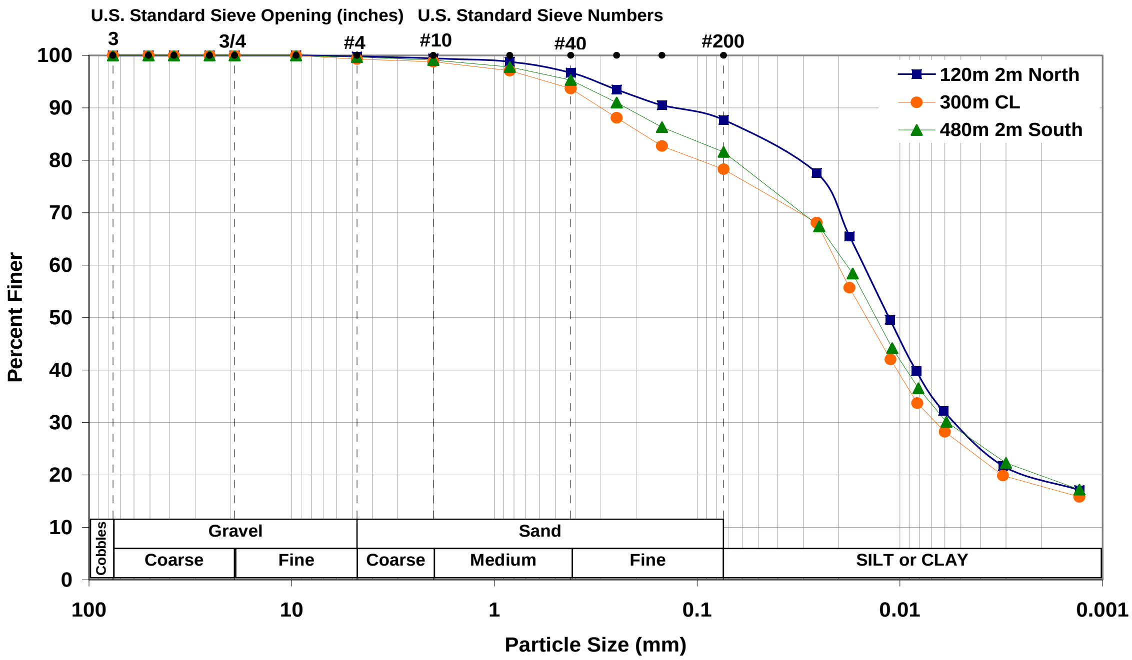


Figure B-3. Gradation analysis for 600-mm (24-in.) soil samples.

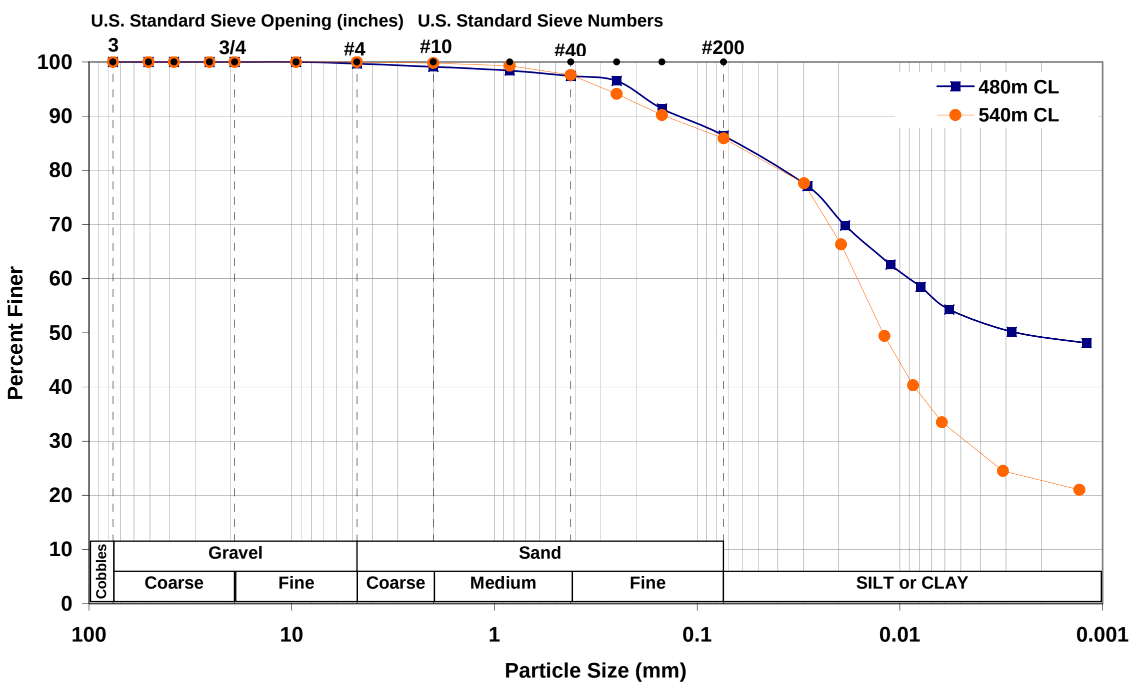


Figure B-4. Gradation analysis for 305- to 660-mm (12- to 26-in.) soil samples.

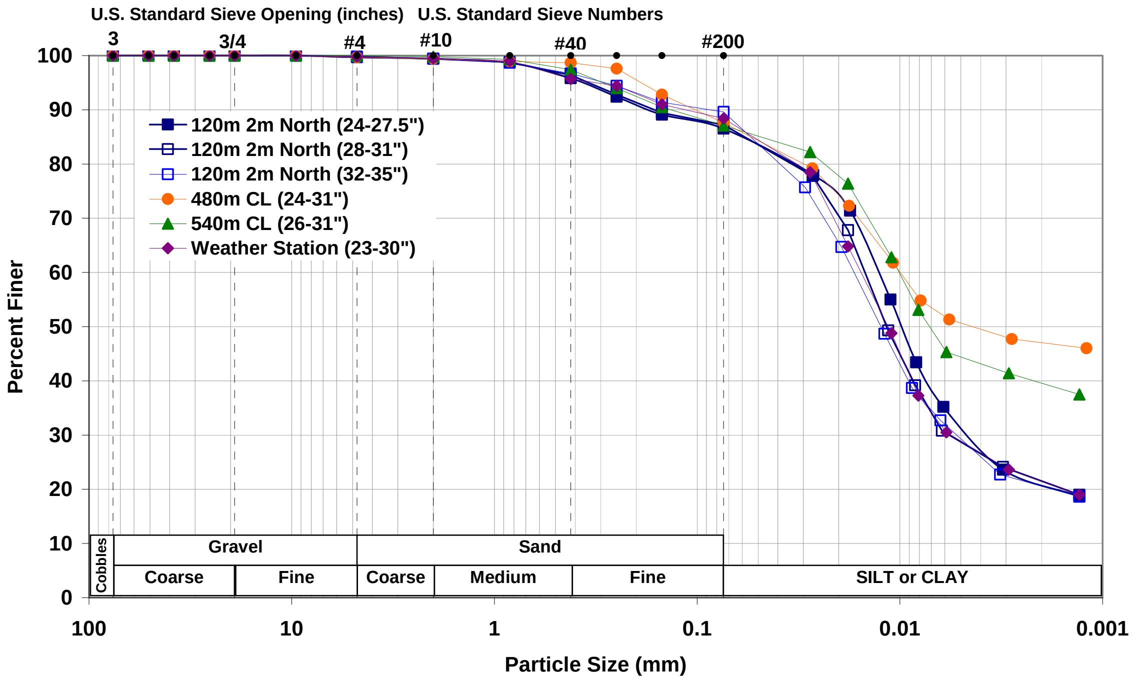


Figure B-5. Gradation analysis for 610- to 890-mm (24- to 35-in.) soil samples.

Table B-2. Volumetric soil moisture measurements made at the North Vernon Airport RAS during the spring IOP1.

Date	Station	Depth (mm)	Depth (inches)	Reading 1 (Vol%)	Reading 2 (Vol%)	Reading 3 (Vol%)	Reading 4 (Vol%)	Reading 5 (Vol%)	Average (Vol%)	Median (Vol%)	Reading 1 (mV)	Reading 2 (mV)	Reading 3 (mV)	Reading 4 (mV)	Reading 5 (%)	COMMENTS
4/19/05	120 2N	0	0	35.5	28.9	30.9			29.9	30.9						mV readings not recorded
4/19/05	120 2N	76	3	31.0	31.8	30.0			30.9	31.0						
4/19/05	120 2N	152	6	30.4	28.6	29.1	30.1		29.6	29.6						
4/19/05	120 2N	305	12	38.1	39.2	37.5			38.3	38.1						
4/19/05	120 2N	457	18	37.3	36.4	38.6			37.4	37.3						
4/19/05	120 2N	610	24	39.8	38.7	42.6	41.8		40.7	40.8						
4/19/05	180 2S	0	0	29.4	30.0	29.4			29.6	29.4						
4/19/05	180 2S	76	3	30.3	29.3	29.8			29.8	29.8						
4/19/05	180 2S	152	6	30.6	30.0	30.2			30.3	30.2						
4/19/05	180 2S	305	12	36.4	36.2	36.6			36.4	36.4						
4/19/05	240 2N	0	0	29.9	32.2	29.0	13.0		30.4	29.5						
4/19/05	240 2N	76	3	31.4	28.8	30.7	19.7		30.3	29.8						
4/19/05	240 2N	152	6	31.0	31.9	30.1			31.0	31.0						
4/19/05	240 2N	305	12	34.3	36.0	35.1			35.1	35.1						
4/19/05	300 CL	0	0	26.1	28.5	30.2			28.3	28.5						
4/19/05	300 CL	76	3	30.8	30.3	32.4			31.2	30.8						
4/19/05	300 CL	152	6	32.6	28.6	31.6	33.8	31.1	32.3	31.6						
4/19/05	300 CL	305	12	36.6	35.8	36.3			36.2	36.3						
4/19/05	300 CL	457	18	38.1	39.1	37.7			38.3	38.1						
4/19/05	300 CL	610	24	40.5	40.4	39.4			40.1	40.4						
4/19/05	480 2S	0	0	32.1	29.6	31.1			30.9	31.1						
4/19/05	480 2S	76	3	28.9	29.3	30.6			29.6	29.3						
4/19/05	480 2S	152	6	27.0	30.3	31.9			29.7	30.3						
4/19/05	480 2S	305	12	35.3	30.2	34.0			33.2	34.0						
4/19/05	480 2S	457	18	33.1	36.1	34.8	34.5		34.6	34.7						
4/19/05	480 2S	610	24	38.2	38.6	36.4			37.7	38.2						

Table B-3. Cone penetrometer readings at North Vernon Municipal Airport during spring IOP1.

Surface Soil Strength Measurements (Cone penetrometer)

Operator(s):	Chris Berini (Cone Pen), Lynette Barna (reading/recording), Gordon Gooch (recording)
Date:	4/22/2005
Time:	late morning-early afternoon
Note:	Rain during early morning hours

Note: 300+ means the that the reading on the dial exceeded 300 before this depth

Sampling Point:	0m CL	0m CL (2)	15m CL	60m CL	120m CL	120m 2N	120m 2S	150m CL	180m CL	180m 2N	180m 2S	240m CL	240m 2N	300m CL	300m CL (2)	360m CL	360m 2N	360m 2S	420m CL	480m CL	480m 2N	480m 2S	540m CL	540m 2N	540m 2S	585m CL	600m CL
	0	**0**	**15**	**60**	**120**	**120**	**120**	**150**	**180**	**180**	**180**	**240**	**240**	**300**	**300**	**360**	**360**	**360**	**420**	**480**	**480**	**480**	**540**	**540**	**540**	**585**	**600**
Surface Moisture Content (HH2)	29	29	32.5	33.5	37.8	40	34.7	36	35.6	35.4	35.9	35.6	38.1	34.2	36.4	37.4	34.6	36.4	34.3	36.8	35.4	33.8	33.4	34	34	37.3	34.1
Top of Cone	130	80	60	60	50	60	60	60	40	60	60	80	70	80	50	50	50	40	60	70	70	70	60	30	30	50	60
1 inch	140	110	120	70	110	100	100	110	110	80	140	110	150	110	120	100	70	100	90	110	110	150	110	70	80	80	100
2 inches	170	120	170	115	125	160	95	125	175	90	170	140	180	105	150	120	80	150	100	150	120	180	125	150	180	160	150
3 inches	250	140	225	125	120	200	120	135	230	100	200	160	190	110	200	160	100	190	140	180	160	240	150	220	220	200	240
4 inches	300+	250	300+	180	140	230	220	170	280	200	220	165	260	150	220	200	160	200	225	240	190		200	280	260	300	
5 inches		300+		220	175	280	280	190	290	240	230	185	290	200	260	240	220	220	230	260	220		240				
6 inches				260	175	300	240	210	300+	280	250	185	300+	250	300+	280	260	270	300	300	260		230				
7 inches				300+	250		220	240			300+	220		280		300+	300+	300+	300+		280		240				
8 inches					300+		250	300				220		260									280				
9 inches							240					180		280													
10 inches												240		300+													
11 inches												300+															
12 inches												*Squirrely data															

Table B-4. Volumetric soil moisture measurements made at the North Vernon Airport RAS during the summer IOP1.

Date	Station	Depth (mm)	Depth (in.)	Reading 1 (Vol%)	Reading 2 (Vol%)	Reading 3 (Vol%)	Reading 4 (Vol%)	Average (Vol%)	Median (Vol%)	Reading 1 (mV)	Reading 2 (mV)	Reading 3 (mV)	Reading 4 (mV)	Comments
8/1/2005	0 CL	0	0	9.3	13.9	12.0		11.7	12.0	264	359	320		
8/1/2005	0 CL	152	6	22.7				22.7	22.7	571				
8/1/2005	0 CL	305	12	24.6	27.4	24.9		25.6	24.9	610	668	617		
8/1/2005	0 CL	610	24	19.6	22.0	22.4	21.9	21.5	22.0	501	555	564	553	
8/1/2005	0 CL	864	34	16.8	18.6	20.6		18.7	18.6	432	478	523		
8/2/2005	0 10 N	0	0	19.8	17.0	17.9		18.2	17.9	505	436	459		
8/2/2005	0 10 N	305	12	21.2	14.7	21.2	24.6	22.3	21.2	536	378	537	612	
8/2/2005	0 10 N	610	24	24.4	26.1	26.0		25.5	26.0	608	641	639		
8/2/2005	0 10 N	838	33	25.9	26.9	30.7		27.8	26.9	638	658	729		
8/2/2005	0 10 S	0	0	6.8	4.4	9.0		6.7	6.8	212	169	256		
8/2/2005	0 10 S	305	12	12.4	13.6	16.0		14.0	13.6	329	354	412		
8/2/2005	0 10 S	686	27	18.0	19.5	19.5		19.0	19.5	463	499	499		
8/2/2005	0 10 S	787	31	19.3	21.6	22.0		21.0	21.6	494	545	554		
8/1/2005	15 CL	0	0	5.8	8.5	10.8		8.4	8.5	194	246	294		
8/1/2005	15 CL	305	12	6.6	7.3	6.5		6.8	6.6	208	220	206		
8/1/2005	15 CL	610	24	18.9	16.8	17.2		17.6	17.2	485	431	442		
8/1/2005	15 CL	813	32	18.7	20.2	21.3		20.1	20.2	481	514	538		
8/1/2005	60 CL	0	0	9.6	9.6	9.8		9.7	9.6	270	269	273		
8/1/2005	60 CL	305	12	17.9	16.8	17.4		17.4	17.4	460	432	447		
8/1/2005	60 CL	610	24	18.9	18.7	19.5		19.0	18.9	485	479	498		

Table B-4 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the summer IOP1.

Date	Station	Depth (mm)	Depth (in.)	Reading 1 (Vol%)	Reading 2 (Vol%)	Reading 3 (Vol%)	Reading 4 (Vol%)	Average (Vol%)	Median (Vol%)	Reading 1 (mV)	Reading 2 (mV)	Reading 3 (mV)	Reading 4 (mV)	Comments
8/1/2005	60 CL	826	33	25.2	27.2	25.9		26.1	25.9	623	663	637		
8/1/2005	120 CL	0	0	14.3	15.5	13.8		14.5	14.3	369	399	357		
8/1/2005	120 CL	330	13	22.1	20.2	24.0		22.1	22.1	557	514	598		
8/1/2005	120 CL	610	24	23.9	28.8	27.8		26.8	27.8	596	696	676		
8/1/2005	120 CL	864	34	17.1	21.6	23.6		22.6	21.6	441	545	590		
8/1/2005	150 CL	0	0	8.1	8.5	7.2		7.9	8.1	238	240	219		
8/1/2005	150 CL	305	12	12.0	16.0	13.8		13.9	13.8	320	411	357		
8/1/2005	150 CL	610	24	15.0	18.6	17.8		17.1	17.8	387	477	457		
8/1/2005	150 CL	762	30	19.3	22.2	25.6		22.4	22.2	493	559	631		
8/2/2005	150 10 N	0	0	10.1	7.0	7.9		8.3	7.9	279	216	233		
8/2/2005	150 10 N	305	12	9.9	13.1	9.4		10.8	9.9	274	344	266		
8/2/2005	150 10 N	635	25	17.6	18.5	18.6		18.2	18.5	452	474	479		
8/2/2005	150 10 N	787	31	21.5	23.4	23.7		22.9	23.4	544	586	594		
8/2/2005	150 10 S	0	0	4.7	9.7	7.5		7.3	7.5	175	272	22		
8/2/2005	150 10 S	305	12	11.3	13.9	17.3		14.2	13.9	306	358	444		
8/2/2005	150 10 S	610	24	14.9	19.0	19.9		19.5	19.0	386	488	507		
8/2/2005	150 10 S	787	31	19.6	21.5	20.3		20.5	20.3	500	544	516		
8/1/2005	180 CL	0	0	10.0	11.6	10.6		10.7	10.6	278	312	289		
8/1/2005	180 CL	305	12	13.3	13.6	18.4		13.5	13.6	247	352	473		
8/1/2005	180 CL	610	24	18.0	22.5	19.1		20.3	19.1	461	566	489		
8/1/2005	180 CL	787	31	18.4	17.7	23.1		18.1	18.4	472	455	579		

Table B-4 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the summer IOP1.

Date	Station	Depth (mm)	Depth (in.)	Reading 1 (Vol%)	Reading 2 (Vol%)	Reading 3 (Vol%)	Reading 4 (Vol%)	Average (Vol%)	Median (Vol%)	Reading 1 (mV)	Reading 2 (mV)	Reading 3 (mV)	Reading 4 (mV)	Comments
8/1/2005	240 CL	0	0	14.7	9.1	13.1	13.0	12.5	13.1	379	259	342	341	
8/1/2005	240 CL	305	12	13.9	14.4	21.7	19.7	14.2	17.1	361	372	548	504	
8/1/2005	240 CL	610	24	24.2	26.6	29.2		26.7	26.6	603	651	702		
8/1/2005	240 CL	838	33	21.4	25.1	27.5		24.7	25.1	542	621	671		
8/1/2005	300 CL	0	0	10.7	13.2	14.3		12.7	13.2	292	345	368		
8/1/2005	300 CL	305	12	16.1	15.8	16.0		16.0	16.0	416	406	413		
8/1/2005	300 CL	610	24	19.4	21.2	24.1		21.6	21.2	497	536	600		
8/1/2005	300 CL	762	30	23.7	23.4	26.8		24.6	23.7	592	587	656		
8/2/2005	300 10 N	0	0	11.1	12.5	10.0		11.2	11.1	302	330	276		
8/2/2005	300 10 N	305	12	16.2	17.6	13.2		15.7	16.2	417	453	345		
8/2/2005	300 10 N	622	25	20.6	24.7	28.7		24.7	24.7	522	613	694		
8/2/2005	300 10 N	813	32	24.3	29.7	31.9	30.2	30.6	30.0	604	712	751	721	
8/2/2005	300 10 S	0	0	10.2	10.2	9.2		9.9	10.2	281	282	262		
8/2/2005	300 10 S	330	13	13.3	12.1	16.9		14.1	13.3	346	322	436		
8/2/2005	300 10 S	635	25	17.5	24.3	24.5		24.4	24.3	449	606	609		
8/2/2005	300 10 S	787	31	20.3	23.4	23.1		22.3	23.1	517	587	578		
8/1/2005	360 CL	0	0	14.5	14.2	9.8	14.5	14.4	14.4	374	367	251	374	
8/1/2005	360 CL	305	12	15.5	15.7	19.3		16.8	15.7	406	405	493		
8/1/2005	360 CL	660	26	19.1	23.4	22.8		21.8	22.8	489	585	573		
8/1/2005	360 CL	787	31	21.9	27.1	24.2		24.4	24.2	551	562	603		
8/1/2005	420 CL	0	0	13.0	12.2	11.2		12.1	12.2	342	324	302		

Table B-4 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the summer IOP1.

Date	Station	Depth (mm)	Depth (in.)	Reading 1 (Vol%)	Reading 2 (Vol%)	Reading 3 (Vol%)	Reading 4 (Vol%)	Average (Vol%)	Median (Vol%)	Reading 1 (mV)	Reading 2 (mV)	Reading 3 (mV)	Reading 4 (mV)	Comments
8/1/2005	420 CL	305	12	15.9	14.0	15.3		15.1	15.3	409	362	394		
8/1/2005	420 CL	610	24	22.4	22.1	24.4		23.0	22.4	562	557	606		
8/1/2005	420 CL	762	30	17.0	24.8	22.4	24.9	24.0	23.6	437	615	563	617	
8/2/2005	450 10 N	0	0	12.7	14.0	11.0		12.6	12.7	334	361	298		
8/2/2005	450 10 N	305	12	15.5	16.0	15.5		15.7	15.5	401	412	399		
8/2/2005	450 10 N	610	24	22.0	29.8	28.0		28.9	28.0	554	731	681		
8/2/2005	450 10 N	813	32	28.2	32.2	31.2		30.5	31.2	684	755	738		
8/2/2005	45010 S	0	0	10.8	11.3	8.3		10.1	10.8	294	304	242		
8/2/2005	450 10 S	305	12	12.9	12.7	16.5		14.0	12.9	338	334	424		
8/2/2005	45010 S	610	24	18.3	23.3	23.0		23.2	23.0	471	584	578		
8/2/2005	450 10 S	787	31	24.2	24.8	24.2		24.4	24.2	603	615	604		
8/2/2005	480 CL	0	0											MISSED READING
8/2/2005	480 CL	305	12	17.9	14.6	15.8		16.1	15.8	460	377	406		
8/2/2005	480 CL	610	24	19.3	19.5	21.2		20.0	19.5	493	497	536		
8/2/2005	480 CL	787	31	24.1	27.7	26.2		26.0	26.2	661	674	644		
8/2/2005	540 CL	0	0	13.6	9.7	13.3	14.3	12.7	13.5	353	270	347	369	
8/2/2005	540 CL	305	12	17.4	13.0	16.6		15.7	16.6	448	340	428		
8/2/2005	540 CL	660	26	19.2	20.2	20.3		19.9	20.2	491	514	516		
8/2/2005	540 CL	787	31	22.4	22.9	22.3		22.5	22.4	575	575	562		
8/2/2005	585 CL	0	0	14.6	13.9	11.2		13.2	13.9	377	359	302		
8/2/2005	585 CL	305	12	21.1	15.8	19.5	19.0	18.9	19.3	535	407	498	486	
8/2/2005	585 CL	610	24	23.9	24.8	26.2		25.0	24.8	596	615	643		

Table B-4 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the summer IOP1.

Date	Station	Depth (mm)	Depth (in.)	Reading 1 (Vol%)	Reading 2 (Vol%)	Reading 3 (Vol%)	Reading 4 (Vol%)	Average (Vol%)	Median (Vol%)	Reading 1 (mV)	Reading 2 (mV)	Reading 3 (mV)	Reading 4 (mV)	Comments
8/2/2005	585 CL	762	30	26.0	29.6	31.1		28.9	29.6	640	709	737		
8/2/2005	600 10 N	0	0	10.5	15.9	15.5		15.7	15.5	288	410	400		
8/2/2005	600 10 N	305	12	17.3	16.7	19.1		17.7	17.3	444	430	489		
8/2/2005	600 10 N	610	24	21.8	33.7	30.5	29.3	31.2	29.9	550	782	726	705	
8/2/2005	600 10 N	813	32	29.2	31.1	33.6		31.3	31.1	704	735	781		
8/2/2005	600 CL	0	0	14.3	13.5	12.7		13.5	13.5	370	350	33		
8/2/2005	600 CL	305	12	18.7	16.8	17.5		17.7	17.5	480	432	450		
8/2/2005	600 CL	635	25	21.5	21.5	24.9		22.6	21.5	543	542	618		
8/2/2005	600 CL	787	31	26.4	29.7	30.1		28.7	29.7	647	712	719		
8/2/2005	600 10 S	0	0	13.6	12.5	10.6		12.2	12.5	353	331	290		
8/2/2005	600 10 S	305	12	12.9	11.1	10.8		11.6	11.1	338	301	294		
8/2/2005	600 10 S	610	24											MISSED READING
8/2/2005	600 10 S	813	32	20.3	23.3	21.3		21.6	21.3	517	584	539		

Table B-5. North Vernon Airport RAS summary of DCP test results from summer IOP2.

Station	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
0 m 10 m North	8/2/2005	14.69	38.51	26.15	8.65	7.89	6.47		32.65	20.76	7.77	
0 m 10 m South	8/2/2005	8.92	24.72	21.08	23.03	20.87	5.28		21.48	22.11	20.87	
0 m Centerline	8/1/2005	20.54	35.57	12.86	8.25	4.40			27.48	10.55	4.40	
120 m 10 m North	8/2/2005	14.54	25.59	15.75	16.26	13.13			22.13	16.01	13.13	
120 m 10 m South	8/2/2005	29.18	26.75	19.17	14.46	12.13			27.80	17.03	12.13	
120 m Centerline	8/1/2005	5.72	6.07	6.64	5.11	3.27			5.92	5.96	3.27	
15 m Centerline	8/1/2005	4.49	26.95	35.79	19.53	12.63			16.97	28.40	12.63	
150 10 m North	8/2/2005	25.22	38.57	19.90	13.70	9.33	6.47		33.56	17.16	9.33	
150 10 m South	8/2/2005	15.74	25.98	20.36	11.97	7.40			22.50	17.04	7.40	
150 m Centerline	8/1/2005	12.76	21.49	19.63	13.95	7.95			18.72	17.11	7.95	
180 m Centerline	8/1/2005	12.39	19.60	12.51	7.14	5.80			16.89	10.52	5.80	
240 m Centerline	8/1/2005	16.38	21.46	8.90	3.51	1.91	2.43		19.57	7.22	1.91	
300 m 10 m North	8/1/2005	19.33	28.45	17.03	9.47	5.69	3.50		25.46	14.00	5.45	
300 m 10 m South	8/1/2005	20.87	31.50	16.69	8.31	5.84			27.35	13.39	5.84	
300 m Centerline	8/1/2005	10.48	23.07	12.95	13.39	7.74			19.27	13.17	7.74	
360 m Centerline	8/1/2005	13.41	22.86	12.92	6.84	5.00			19.12	10.67	5.00	
420 m Centerline	8/1/2005	17.51	27.58	19.32	15.70	11.03			23.92	17.67	11.03	
450 m 10 m North	8/2/2005	16.45	21.12	20.36	7.74	3.25	5.63		19.12	16.95	3.25	
450 m 10 m South	8/2/2005	9.61	24.77	20.76	15.03	10.05			20.70	18.26	10.05	
480 m 10 m North	8/2/2005	13.95	37.44	61.00	40.26	23.38	13.08		32.09	52.29	23.03	
480 m 10 m South	8/2/2005	15.50	26.64	20.88	16.19	14.63	8.31		23.25	18.72	14.26	
480 m Centerline	8/2/2005	5.15	32.38	18.83	16.40	9.25			27.43	17.75	9.25	

Table B-5 (cont'd). North Vernon Airport RAS summary of DCP test results from summer IOP2.

Station	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
540 m Centerline	8/2/2005	27.80	30.50	21.75	16.03	7.14			29.30	19.30	7.14	
585 m Centerline	8/2/2005	23.05	26.86	10.86	5.14	3.16	3.22		25.28	9.12	3.17	
60 m Centerline	8/1/2005	13.43	19.64	10.93	6.86	4.80			16.79	9.06	4.80	
600 m 10 m North	8/2/2005	16.23	24.74	20.62	7.28	3.35			21.79	17.57	3.35	
600 m 10 m South	8/2/2005	16.16	13.12	8.21	8.04	3.32			14.81	8.13	3.32	
600 m Centerline	8/2/2005	6.71	16.77	15.53	9.14	4.09			13.53	13.21	4.09	

Table B-6. North Vernon Airport RAS summary of Clegg hammer testing from summer IOP2.

Location		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Calculated CBR	Average	Median
0	CL	19.0	23.8	27.8	27.7			11.3		
0	CL	18.5	24.2	28.7	28.6			12.0		
0	CL	23.6	27.5	29.0	31.9			14.9	12.7	12.0
0	10N	13.1	17.0	18.3	19.7			5.8		
0	10N	19.1	20.6	26.0	26.8			10.6		
0	10N	7.9	13.2	16.9	18.1			4.9	7.1	5.8
0	10S	19.0	22.8	18.9						
0	10S	12.5	20.1	22.5	22.5			7.5		
0	10S	19.2	23.8	24.9	26.9			10.7		
0	10S	30.0	38.2	41.9	42.4			26.0	14.7	10.7
15	CL	15.7	17.1	18.7	18.7			5.3		
15	CL	18.3	24.4	26.1	26.1			10.1		
15	CL	12.6	17.0	19.2	21.5	21.4		6.9	7.4	6.9
60	CL	12.0	16.9	19.7	21.9			7.2		
60	CL	6.7	10.6	12.9	13.8	14.7	16.0	2.9		
60	CL	11.2	15.5	17.0	18.2	19.0		5.0	5.0	5.0
120	CL	9.0	10.7	15.5	13.2					
120	CL	6.4	8.7	8.8	9.2	9.3		1.4		
120	CL	8.7	10.8	12.4	11.5	13.6				
120	CL	21.5	24.0	22.9	21.8	23.1			1.4	1.4
120	10N	18.4	21.2	23.8	24.4	23.2		8.8		
120	10N	21.2	26.9	22.9	27.7					
120	10N	10.5	17.2	18.1	19.2			5.5	7.2	7.2
120	10S	17.6	23.8	23.7	25.9			9.9		
120	10S	21.1	25.1	27.9	22.5					
120	10S	15.3	14.4	15.6	15.9					
120	10S	16.3	27.1	29.2	33.2			16.1	13.0	13.0
150	CL	11.8	13.1	14.0	14.0			3.0		
150	CL	12.2	12.1	12.1	12.2			2.3		
150	CL	15.3	16.0	15.9	15.3				2.7	2.7
150	10N	18.8	23.5	25.0	26.3			10.2		
150	10N	21.2	26.4	17.9						
150	10N	13.4	17.6	20.8	23.6			8.3		
150	10N	12.5	14.7	17.5	18.8			5.3	7.9	8.3
150	10S	15.7	15.8	14.5	13.3					

Table B-6 (cont'd). North Vernon Airport RAS summary of Clegg hammer testing from summer IOP2.

Location		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Calculated CBR	Average	Median
150	10 S	14.6	19.6	18.1	21.3					
150	10 S	13.1	18.5	21.5	26.8			10.6		
150	10 S	8.4	13.4	16.2	14.8					
150	10 S	12.1	16.6	14.7	15.0			3.4	7.0	7.0
180	CL	17.1	20.9	24.0	20.4					
180	CL	18.3	21.9	23.6	23.3					
180	CL	14.0	18.2	17.7	18.5			5.2	5.2	5.2
240	CL	16.8	21.5	21.1	21.7					
240	CL	20.8	24.4	24.5	24.8			9.1		
240	CL	21.8	28.2	32.7	30.9				9.1	9.1
300	CL	11.0	13.3	14.7	16.4			4.1		
300	CL	8.5	13.7	17.6	19.8			5.9		
300	CL	18.0	22.1	23.1	23.6			8.3	6.1	5.9
300	10 N	11.2	14.6	16.2	17.4			4.6		
300	10 N	13.9	19.5	19.1	18.8					
300	10 N	29.7	31.3	31.4	28.1					
300	10 N	20.7	26.4	28.6	31.3			14.3	9.5	9.5
300	10 S	1.0	16.3	17.5	18.2	19.6		5.0		
300	10 S	19.0	24.7	24.2	25.3					
300	10 S	13.7	15.7	16.6	18.8			5.3	5.2	5.2
360	CL	19.7	32.2	30.6	33.6					
360	CL	20.6	26.1	27.0	29.0			12.4		
360	CL	14.0	17.2	19.0	21.5			6.9	9.6	9.6
420	CL	17.9	23.4	21.7	24.3					
420	CL	16.2	23.3	24.6	23.2					
420	CL	20.2	24.0	28.1	30.8			13.9	13.9	13.9
450	10 N	21.7	24.7	30.3	28.1					
450	10 N	24.7	31.6	30.4	33.3					
450	10 N	14.0	19.0	17.6	18.0					
450	10 N	13.6	18.9	20.0	16.5					
450	10 N	19.9	27.5	31.2	31.3			14.3	14.3	14.3
450	10 S	16.5	24.5	27.2	28.9			12.3		
450	10 S	12.9	19.0	24.3	28.0			11.5		
450	10 S	20.9	25.1	24.6	22.5				11.9	11.9

Table B-6 (cont'd). North Vernon Airport RAS summary of Clegg hammer testing from summer IOP2.

Location		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Calculated CBR	Average	Median
480	CL	21.3	23.4	22.6	25.0					
480	CL	21.0	26.6	30.0	32.5			15.4		
480	CL	14.1	18.2	20.5	21.5			6.9	11.2	11.2
480	10 N	17.3	17.5	17.5	17.0					
480	10 N	20.4	22.6	25.7	26.8			10.6		
480	10 N	18.4	21.1	24.1	20.1					
480	10 N	13.1	13.1	14.7	14.3				10.6	10.6
480	10 S	15.7	22.8	26.9	27.2			10.9		
480	10 S	20.1	21.8	20.1	20.7					
480	10 S	11.9	16.3	16.0	16.2				10.9	10.9
540	CL	1.5	23.4	22.9	22.5	20.2				
540	CL	24.2	31.9	33.7	33.2					
540	CL	22.9	29.4	33.8	37.0			19.9		
540	CL	18.8	23.3	22.9	22.5				19.9	19.9
585	CL	18.4	21.6	22.5	25.2			9.4		
585	CL	30.7	37.0	38.8	36.0					
585	CL	23.7	32.4	34.6	35.8			18.7		
585	CL	24.1	30.9	32.6	33.2			16.1	14.7	14.7
600	10 S	18.8	19.2	21.7	19.0					
600	10 S	17.8	21.6	22.2	23.0			7.9		
600	10 S	13.1	18.0	19.7	21.7			7.0		
600	10 S	20.1	25.2	25.0	25.0				7.4	7.4
600	10 N	16.0	18.2	23.5	26.7			10.5		
600	10 N	13.3	21.4	21.6	21.0					
600	10 N	14.0	21.2	24.1	24.7			9.0	9.8	9.8
600	CL	20.3	25.5	29.3	31.6			14.6		
600	CL	17.2	23.6	26.8	24.1					
600	CL	12.0	13.7	20.3	22.9			7.8	11.2	11.2

Table B-7. Volumetric soil moisture measurements made at the North Vernon Airport RAS during the fall IOP3.

Station	Depth	Depth	Average	Median
	(mm)	(in.)	(%)	(%)
0 CL	0	0	34.9	35.3
0 CL	152	6	28.8	29.0
0 CL	305	12	28.2	28.7
0 CL	610	24	36.4	36.3
0 CL	762	30	36.5	36.9
0 10 N	0	0	35.2	35.6
0 10 N	152	6	29.7	29.5
0 10 N	305	12	23.4	23.4
0 10 N	610	24	28.4	28.4
0 10 N	762	30	29.0	28.4
0 10 S	0	0	32.5	32.3
0 10 S	152	6	28.7	29.5
0 10 S	305	12	29.2	29.7
0 10 S	610	24	27.8	27.4
0 10 S	762	30	28.7	29.7
15 CL	0	0	32.6	33.2
15 CL	152	6	29.5	29.5
15 CL	305	12	29.3	29.2
15 CL	610	24	33.0	33.4
15 CL	762	30	34.3	34.2
60 CL	0	0	30.5	30.8
60 CL	152	6	26.4	26.4
60 CL	305	12	25.9	25.9
60 CL	610	24	27.9	27.9
60 CL	762	30	29.1	29.0
120 10 N	0	0	32.5	32.6
120 10 N	152	6	27.2	27.4
120 10 N	305	12	29.2	29.5
120 10 N	610	24	31.6	31.2
120 10 N	762	30	33.6	34.2
120 CL	0	0	35.8	35.4
120 CL	152	6	29.0	29.3
120 CL	305	12	28.9	27.7
120 CL	610	24	27.5	27.2

Table B-7 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the fall IOP3.

Station	Depth	Depth	Average	Median
	(mm)	(in.)	(%)	(%)
120 CL	787	31	34.0	33.8
120 10 S	0	0	28.7	29.3
120 10 S	152	6	28.5	28.2
120 10 S	305	12	27.0	27.8
120 10 S	610	24	32.5	33.1
120 10 S	787	31	31.9	31.8
150 CL	0	0	29.1	28.4
150 CL	152	6	27.2	27.2
150 CL	305	12	27.2	26.8
150 CL	610	24	27.1	27.0
150 CL	762	30	31.2	31.6
150 10 N	0	0	28.0	27.9
150 10 N	152	6	28.2	27.7
150 10 N	305	12	30.4	30.1
150 10 N	610	24	31.7	32.1
150 10 N	762	30	33.2	33.8
150 10 S	0	0	27.6	27.2
150 10 S	152	6	28.3	28.4
150 10 S	305	12	28.5	28.6
150 10 S	610	24	28.8	27.4
150 10 S	787	31	29.3	29.2
180 CL	0	0	28.6	28.7
180 CL	152	6	27.5	27.4
180 CL	305	12	26.9	27.0
180 CL	610	24	25.7	25.7
180 CL	737	29	27.4	26.9
240 CL	0	0	32.7	33.2
240 CL	152	6	27.5	28.0
240 CL	305	12	31.1	30.4
240 CL	610	24	34.9	34.9
240 CL	762	30	35.9	35.3
300 CL	0	0	37.1	37.6
300 CL	152	6	31.6	32.3
300 CL	406	16	33.0	33.6

Table B-7 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the fall IOP3.

Station	Depth	Depth	Average	Median
	(mm)	(in.)	(%)	(%)
300 CL	610	24	32.1	31.7
300 CL	762	30	34.4	34.1
300 10 N	0	0	30.8	31.3
300 10 N	152	6	28.5	28.5
300 10 N	305	12	31.5	31.4
300 10 N	610	24	34.1	34.6
300 10 N	762	30	36.5	36.6
300 10 S	0	0	30.8	30.4
300 10 S	152	6	26.5	27.3
300 10 S	305	12	31.6	31.1
300 10 S	584	23	28.4	28.4
300 10 S	737	29	28.0	28.3
360 CL	0	0	33.7	33.3
360 CL	152	6	29.2	28.7
360 CL	305	12	26.9	27.2
360 CL	610	24	29.2	28.7
360 CL	762	30	32.7	33.6
420 CL	0	0	33.0	33.4
420 CL	152	6	30.5	30.5
420 CL	305	12	25.7	25.5
420 CL	610	24	24.8	24.8
420 CL	737	29	28.5	28.6
450 10 N	0	0	33.4	33.4
450 10 N	152	6	27.3	26.9
450 10 N	330	13	30.8	30.6
450 10 N	610	24	33.9	33.2
450 10 N	787	31	35.3	35.5
450 CL	0	0	29.2	29.5
450 CL	152	6	26.4	26.5
450 CL	305	12	28.7	28.1
450 CL	610	24	26.5	27.4
450 CL	762	30	29.3	30.0
450 10 S	0	0	33.1	33.6
450 10 S	152	6	30.1	30.3

Table B-7 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the fall IOP3.

Station	Depth (mm)	Depth (in.)	Average (%)	Median (%)
450 10 S	305	12	29.7	29.5
450 10 S	610	24	32.6	32.2
450 10 S	762	30	32.7	32.4
480 10 N	0	0	30.5	30.6
480 10 N	152	6	29.2	29.2
480 10 N	305	12	25.2	23.8
480 10 N	610	24	26.6	26.6
480 10 N	762	30	30.3	30.2
480 CL	0	0	33.1	32.5
480 CL	152	6	28.0	28.4
480 CL	305	12	28.7	28.0
480 CL	610	24	26.5	26.6
480 CL	762	30	30.4	29.7
480 10 S	0	0	33.6	33.7
480 10 S	152	6	29.5	29.7
480 10 S	305	12	23.1	23.7
480 10 S	584	23	30.2	30.0
480 10 S	762	30	34.2	33.7
540 CL	0	0	32.3	32.4
540 CL	152	6	28.3	28.9
540 CL	305	12	28.6	28.7
540 CL	610	24	26.5	26.6
540 CL	813	32	35.3	35.7
585 CL	0	0	35.1	35.3
585 CL	152	6	28.4	28.2
585 CL	305	12	31.2	30.6
585 CL	610	24	28.4	27.9
585 CL	762	30	30.7	30.2
600 10 N	0	0	36.5	35.9
600 10 N	152	6	30.2	30.4
600 10 N	330	13	34.9	34.8
600 10 N	610	24	36.8	36.8
600 10 N	737	29	38.4	38.3
600 CL	0	0	35.1	35.3

Table B-7 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the fall IOP3.

Station	Depth	Depth	Average	Median
	(mm)	(in.)	(%)	(%)
600 CL	152	6	30.8	31.2
600 CL	305	12	31.8	31.7
600 CL	610	24	33.4	32.3
600 CL	813	32	33.1	33.0
600 10 S	0	0	31.1	31.3
600 10 S	152	6	27.4	27.8
600 10 S	305	12	25.2	25.7
600 10 S	610	24	32.2	31.6
600 10 S	737	29	28.0	28.2
SURFACE	0	0	31.8	31.7
MID PIN 8—10	76	3	27.8	27.3
MID PIN 18—20	178	7	26.2	25.1
MID PIN 28—30	279	11	30.8	31.8
MID PIN 38—40	381	15	27.8	27.7
MID PIN 58—60	584	23	27.6	27.1
MID PIN 76—80	787	31	30.2	30.7

Table B-8. North Vernon Airport RAS DCP test results from fall IOP3.

		Average CBR within 15-cm bins							Average CBR within 30-cm bins			
Station	Date	0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
0 m 10 m North	11/2/2005	7.73	18.35	11.04	11.03	6.00	4.13		13.52	11.04	4.88	
0 m 10 m South	11/2/2005	6.05	17.13	13.71	10.65	10.15	4.92	3.65	13.43	12.18	8.14	3.65
0 m Centerline	11/2/2005	4.71	10.66	10.65	8.87	8.57	9.59		8.68	9.76	9.08	
120 m 10 m North	11/2/2005	2.90	5.20	4.85	10.68	9.58	6.91		3.88	7.76	8.09	
120 m 10 m South	11/2/2005	6.20	13.40	8.90	9.21	8.17	4.88		9.40	9.04	6.37	
120 m Centerline	11/2/2005	4.57	6.79	7.13	6.92	8.01	10.27		5.68	7.03	9.23	
15 m Centerline	11/2/2005	4.00	8.77	11.59	7.81	7.90	6.42		7.34	10.14	7.23	
150 m 10 m North	11/2/2005	4.00	7.83	6.08	4.76	6.69	6.77		5.92	5.42	6.73	
150 m 10 m South	11/2/2005	4.90	10.36	7.27	8.28	5.92	5.33	4.56	7.63	7.78	5.58	4.56
150 m Centerline	11/2/2005	4.35	8.72	4.50	3.80	6.47	7.51		6.53	4.15	6.90	
180 m Centerline	11/2/2005	3.74	9.96	7.63	4.92	3.60	3.44	4.44	7.70	6.73	3.50	4.44
240 m Centerline	11/2/2005	3.66	6.18	5.27	3.57	4.00	4.67		5.17	4.70	4.40	
300 m 10 m North	11/2/2005	3.33	6.18	4.86	3.80	3.42	3.17		5.04	4.41	3.29	
300 m 10 m South	11/2/2005	5.13	9.80	3.92	4.94	8.40	7.17	10.19	7.64	4.50	7.78	10.19
300 m Centerline	11/2/2005	4.69	8.40	4.50	2.13	3.34	4.11		6.92	3.71	3.65	
360 m Centerline	11/2/2005	5.61	10.21	4.73	7.10	7.25	3.17	2.16	8.29	6.15	5.43	2.16
420 m 10 m North	11/2/2005	7.11	11.82	7.78	5.50	7.59	5.76		9.25	6.64	6.76	
420 m Centerline	11/2/2005	7.28	10.54	11.74	9.31	5.81	6.19		9.18	10.52	6.04	
450 m 10 m North	11/2/2005	4.22	9.08	4.13	4.05	4.30	5.44	8.31	6.87	4.08	5.15	8.31
450 m 10 m South	11/2/2005	4.28	9.21	8.13	5.21	3.71	3.13		6.97	6.84	3.40	
450 m Centerline	11/2/2005	7.28	10.54	11.74	9.31	5.81	6.19		9.18	10.52	6.04	
480 m 10 m North	11/2/2005	8.90	11.49	27.83	18.24	7.39	8.11		10.49	23.84	7.75	

Table B-8 (cont'd). North Vernon Airport RAS DCP test results from fall IOP3.

Station	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
480 m 10 m South	11/2/2005	5.09	19.55	14.66	13.73	10.06	5.84	4.01	13.99	14.23	8.18	4.01
480 m Centerline	11/2/2005	4.10	13.18	16.75	8.72	6.32	7.44	5.82	10.15	13.18	6.83	5.82
540 m Centerline	11/2/2005	6.05	8.97	9.87	8.45	4.09	3.38		7.51	9.32	3.70	
585 m Centerline	11/2/2005	3.52	7.29	7.10	6.09	4.10	10.49	3.65	5.92	6.72	7.75	3.65
60 m Centerline	11/2/2005	3.94	11.45	10.59	11.11	8.62	4.85		8.56	10.83	6.74	
600 m 10 m North	11/2/2005	3.95	8.25	5.19	2.05	3.69	5.10		5.57	3.39	4.39	
600 m 10 m South	11/2/2005	5.16	13.15	16.95	7.57	6.50	10.51	8.31	10.30	12.26	8.97	8.31
600 m Centerline	11/2/2005	3.79	7.08	8.53	3.92	3.91	5.29	6.02	5.77	6.61	4.76	6.02
Weather station (outside of fenced area)	11/3/2005	5.55	11.75	14.05	10.33	10.40	6.05		9.87	12.47	8.95	

Table B-9. North Vernon Airport RAS average cone penetrometer readings, fall IOP3.

Sampling Station	Average CI 6-in. Layers		Average Calculated CBR	
	1–6 in.	6–12 in.	1–6 in.	6–12 in.
0 m CL	112.5	300.0	3.4	6.8
0 m 10 m N	122.7		3.6	
0 m 10 m S	93.1		3.0	
15 m CL	111.4	260.0	3.4	6.2
60 m CL	122.7		3.6	
120 m CL	111.6	240.0	3.4	5.8
120 m 10 m S	123.4		3.7	
120 m 10 m N	124.1		3.7	
150 m CL	108.1		3.3	
150 m 10 m S	109.8	225.0	3.4	5.6
150 m 10 m N	110.6	280.0	3.4	6.5
180 CL	146.7		4.1	
240 CL	74.3		2.6	
300 CL	97.2		3.1	
300 10 N	97.2		3.1	
300 10 S	142.8		4.1	
360 CL	127.3		3.7	
420 CL	111.7		3.4	
420 10 N	105.2		3.3	
450 CL	101.7		3.2	
450 10 N	114.9		3.5	
450 10 S	131.3		3.8	
480 CL	107.1	260.0	3.3	6.2
480 10 S	121.8		3.6	
480 10 N	90.3		2.9	
540 CL	94.9		3.0	
585 CL	97.8		3.1	
600 CL	118.2	220.0	3.6	5.5
600 10 S	132.6		3.8	
600 10 N	125.0		3.7	

Table B-10. North Vernon Airport RAS average and median Clegg hammer readings, fall IOP3.

Location	Site	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Calculated CBR	Average	Median
0	CL	4.1	5.5	5.7	5.8			0.6		
0	CL	8.0	7.4	7.4	8.6					
0	CL	4.7	5.3	5.0	5.5					
0	CL	5.1	5.4	5.3	5.4			0.5		
0	CL	6.5	6.5	6.5	7.0	7.0		0.8	0.6	0.6
0	10 N	6.4	6.4	6.7	6.7			0.8		
0	10 N	5.5	5.7	5.8	5.7			0.6		
0	10 N	5.9	6.4	6.6	6.6			0.7	0.7	0.7
0	10 S	4.9	6.0	7.1	7.7			1.0		
0	10 S	5.2	6.3	6.8	7.6			1.0		
0	10 S	7.1	7.2	7.5	7.9			1.0		
0	10 S	6.4	6.8	6.8	6.8			0.8	0.9	1.0
15	CL	4.8	6.0	6.2	5.8			0.6		
15	CL	6.0	6.7	6.6	6.4			0.7		
15	CL	6.2	7.0	6.8	7.0			0.8		
15	CL	5.5	7.8	7.3	6.9			0.8		
15	CL	5.6	6.8	7.1	7.4			0.9		
15	CL	5.6	6.3	6.1	6.5			0.7		
15	CL	6.5	7.1	6.8	6.4			0.7		
15	CL	4.1	4.8	5.4	5.5			0.5		
15	CL	5.8	6.7	7.1	6.7			0.8		
15	CL	5.8	6.7	6.3	6.5			0.7	0.7	0.7
60	CL	7.8	8.8	8.9	8.5			1.2		
60	CL	6.8	7.5	7.4	7.7			1.0		
60	CL	6.6	7.9	7.6	8.0			1.1		
60	CL	7.0	7.6	8.0	7.9			1.0		

Table B-10 (cont'd). North Vernon Airport RAS average and median Clegg hammer readings, fall IOP3.

Location	Site	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Calculated CBR	Average	Median
60	CL	8.1	8.8	9.1	9.6			1.5	1.2	1.0
120	CL	8.6	8.1	8.1	8.0			1.1		
120	CL	7.8	8.1	8.0	8.5			1.2		
120	CL	7.0	8.1	8.0	8.3			1.1		
120	CL	6.5	6.6	6.7	6.7			0.8	1.0	1.1
120	10 N	6.3	7.5	7.9	8.1			1.1		
120	10 N	6.6	7.5	7.9	8.7			1.2		
120	10 N	7.3	8.0	8.0	8.3			1.1	1.1	1.1
120	10 S	5.7	6.8	7.1	7.2			0.9		
120	10S	4.8	5.9	7.1	7.4			0.9		
120	10 S	4.3	5.4	6.1	6.5			0.7		
120	10 S	4.9	6.0	7.3	7.4			0.9	0.9	0.9
150	CL	4.5	5.5	5.5	6.5			0.7		
150	CL	4.5	5.2	5.7	5.9	6.1		0.6		
150	CL	6.3	7.3	7.2	7.2			0.9	0.7	0.7
150	10 N	5.4	5.9	6.4	6.5			0.7		
150	10 N	6.7	7.5	7.7	7.9			1.0		
150	10 N	6.0	6.4	6.5	6.8			0.8	0.8	0.8
150	10 S	7.4	9.3	9.3	9.3			1.4		
150	10 S	7.8	8.2	8.6	8.7			1.2		
150	10 S	7.6	8.9	9.4	10.6			1.8	1.5	1.4
180	CL	6.6	8.1	8.5	10.0			1.6		
180	CL	7.7	8.3	8.4	8.6			1.2		
180	CL	6.5	8.2	8.5	8.7			1.2	1.3	1.2
240	CL	5.3	5.6	5.4	5.4			0.5		
240	CL	5.6	6.4	6.7	6.3			0.7		

Table B-10 (cont'd). North Vernon Airport RAS average and median Clegg hammer readings, fall IOP3.

Location	Site	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Calculated CBR	Average	Median
240	CL	5.6	5.6	5.6	6.4			0.7		
240	CL	4.6	4.9	4.8	5.7			0.6		
240	CL	4.4	5.1	5.2	5.6			0.6	0.6	0.6
300	CL	4.9	5.8	6.1	6.1			0.6		
300	CL	5	5.7	6.1	6.2			0.7		
300	CL	4.8	6	6	6.3			0.7	0.7	0.7
300	10 N	4.5	5.3	5.4	5.6			0.6		
300	10 N	4.6	4.7	5.2	5.2			0.5		
300	10 N	4.9	5.5	5.6	5.6			0.6	0.5	0.6
300	10 S	7.4	8.4	8.5	8.5			1.2		
300	10 S	6.9	7.6	8.3	8.6			1.2		
300	10 S	7.4	8.3	8.3	8.4			1.2	1.2	1.2
360	CL	7.5	8.8	9.3	9.4			1.4		
360	CL	7.2	8.3	9	9.7			1.5		
360	CL	8.6	8.6	8.5	8.2			1.1		
360	CL	7.3	8.1	8.9	8.8			1.3		
360	CL	7.9	7.8	8.2	8			1.1	1.4	1.4
420	CL	6.4	7	7.4	7.4			0.9		
420	CL	6.4	7.1	8.6	7.5			0.9		
420	CL	6.2	6.8	7.1	7.4			0.9		
420	CL	7.4	7.6	8.2	8.3			1.1	1.0	0.9
450	CL	6.7	6.7	6.7	6.8			0.8		
450	CL	5.9	6.5	6.9	6.9			0.8		
450	CL	5.9	6.7	6.9	7.3			0.9	0.8	0.8
450	10 N	7.1	8.1	8.5	8.5			1.2		
450	10 N	6.2	7.7	7.9	8.2			1.1		
450	10 N	5.5	7.4	8	8.0			1.1		

Table B-10 (cont'd). North Vernon Airport RAS average and median Clegg hammer readings, fall IOP3.

Location	Site	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Calculated CBR	Average	Median
450	10 N	7	7.6	7.6	7.6			1.0		
450	10 N	7.3	8.9	9.2	9.2			1.4	1.1	1.1
450	10 S	4.3	5.5	5.7	5.3			0.5		
450	10 S	5.6	5.8	5.8	5.9			0.6		
450	10 S	5	5.6	6.2	6.2			0.7	0.6	0.6
480	CL	6	6.5	6.7	6.7			0.8		
480	CL	7.2	7.6	8.0	8.0			1.1		
480	CL	5.2	6.1	6.3	6.4			0.7	0.8	0.8
480	10 N	4.3	4.9	5.1	6.5			0.7		
480	10 N	4.2	4.8	5.0	5.4			0.5		
480	10 N	4.2	5.1	5.6	5.9			0.6	0.6	0.6
480	10 S	4.2	4.7	4.9	5.5			0.5		
480	10 S	4.8	5.8	5.8	6.1			0.6		
480	10 S	4.1	5.1	5.7	5.9			0.6	0.6	0.6
540	CL	5.3	5.3	5.8	6			0.6		
540	CL	6.8	7.3	7.4	7.6			1.0		
540	CL	6.7	7.5	8.0	8			1.1	0.9	1.0
585	CL	6.4	6.4	6.5	6.6			0.7		
585	CL	6.2	6.6	6.6	7			0.8		
585	CL	5.4	5.7	5.8	6			0.6	0.7	0.7
600	CL	5.4	5.5	5.5	5.5			0.5		
600	CL	4.5	5.4	5.5	5.8			0.6		
600	CL	3.4	4.6	5.3	5.3			0.5	0.5	0.5
600	10 N	5.0	5.1	5.1	5.1			0.5		
600	10 N	4.7	5.6	5.6	5.6			0.6		
600	10 N	5.7	5.9	5.9	5.9			0.6	0.5	0.6

Table B-10 (cont'd). North Vernon Airport RAS average and median Clegg hammer readings, fall IOP3.

Location	Site	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Calculated CBR	Average	Median
600	10 S	4.9	5.7	6.3	6.3			0.7		
600	10 S	5.9	6.7	7.0	7			0.8		
600	10 S	5.8	6.3	6.8	6.9			0.8	0.8	0.8
Weather station		10.1	12.9	14.2	14.8			3.4		
Weather station		13.3	15.6	15.9	16.1			3.9		
Weather station		8.6	11.6	12.5	13.0			2.6	3.3	3.4

Table B-11. Volumetric soil moisture measurements made at the North Vernon Airport RAS during the winter IOP4.

Date	Station			Depth	Read-ing 1	Read-ing 2	Read-ing 3	Read-ing 4	Read-ing 5	(Using all read-ings)	Median	Read-ing 1	Read-ing 2	Read-ing 3	Read-ing 4	Read-ing 5	
				(in.)	(%)	(%)	(%)	(%)	(%)			(mV)	(mV)	(mV)	(mV)	(mV)	COMMENTS
2/28/2006	0	0	0 CL	0	35.6	36.5	38.3			36.8	36.5	814	828	855			
2/28/2006	0	0	0 CL	6	31.4	29.2	34.0	32.5		31.8	32.0	741	704	787	760		
2/28/2006	0	0	0 CL	12	32.9	34.5	29.2	35.1		32.9	33.7	767	796	703	805		
2/28/2006	0	0	0 CL	27	39.9	40.7	41.7			40.8	40.7	881	894	906			
2/28/2006	0	0	0 CL	30	42.6	42.2	42.0			42.3	42.2	916	911	910			Standing water in bottom of hole at 30 in. water level 28 in
2/28/2006	0	10	0 10 N	0	40.5	42.4	41.0			41.3	41.0	891	914	899			
2/28/2006	0	10	0 10 N	6	31.3	26.8	28.0			28.7	28.0	739	656	690			
2/28/2006	0	10	0 10 N	12	29.1	31.5	30.2			30.3	30.2	700	743	721			
2/28/2006	0	10	0 10 N	24	29.2	32.4	32.6			31.4	32.4	704	759	762			
2/28/2006	0	10	0 10 N	30	28.0	37.7	38.0	36.9		35.2	37.3	632	846	851	834		
2/28/2006	0	10	0 10 S	0	25.8	23.4	37.0	36.6	37.8	32.1	36.6		586	835	828	845	
2/28/2006	0	10	0 10 S	6	32.1	28.5	32.8			31.1	32.1	754	692	766			
2/28/2006	0	10	0 10 S	12	31.9	28.4	23.9	29.9		28.5	29.2	750	690	597	716		
2/28/2006	0	10	0 10 S	24	27.6	34.7	34.1	33.3		32.4	33.7	673	798	788	774		
2/28/2006	0	10	0 10 S	29	37.9	35.7	37.2			36.9	37.2	850	815	838			
2/28/2006	15	0	15 CL	0	40.7	39.2	39.2			39.7	39.2	893	870	870			
2/28/2006	15	0	15 CL	12	30.2	30.2	30.5			30.3	30.2	720	720	725			Air pockets at bottom
2/28/2006	15	0	15 CL	22	34.2	33.3	34.4			34.0	34.2	790	774	799			Clumpy soil at bottom
2/28/2006	15	0	15 CL	30	34.2	36.4	36.3			35.6	36.3	790	826	824			
2/28/2006	60	0	60 CL	0	39.0	40.0	40.1			39.7	40.0	867	883	884			Dense short surface vegetation
2/28/2006	60	0	60 CL	12	33.0	31.4	33.3			32.6	33.0	769	742	774			
2/28/2006	60	0	60 CL	23	36.4	37.4	38.7			37.5	37.4	826	842	863			
2/28/2006	60	0	60 CL	32	40.4	39.7	39.7			39.9	39.7	890	878	879			

Table B-11 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the winter IOP4.

Date	Station			Depth	Read-ing 1	Read-ing 2	Read-ing 3	Read-ing 4	Read-ing 5	(Using all read-ings)	Median	Read-ing 1	Read-ing 2	Read-ing 3	Read-ing 4	Read-ing 5	
				(in.)	(%)	(%)	(%)	(%)	(%)			(mV)	(mV)	(mV)	(mV)	(mV)	COMMENTS
2/28/2006	120	0	120 CL	0	38.3	43.1	43.2			41.5	43.1	856	922	923			Small drainage ditch~2-3ft from flag to west
2/28/2006	120	0	120 CL	12	37.7	37.2	37.5			37.5	37.5	847	839	844			
2/28/2006	120	0	120 CL	23.5	38.2	34.1	36.5	36.4		36.3	36.5	855	788	828	826		
2/28/2006	120	0	120 CL	32	40.5	38.2	38.6	38.5		39.0	38.6	892	855	862	860		
2/28/2006	180	0	180 CL	0	41.0	41.4	41.2			41.2	41.2	899	904	901			
2/28/2006	180	0	180 CL	12	36.0	35.1	35.1			35.4	35.1	820	806	806			
2/28/2006	180	0	180 CL	24	39.6	39.7	38.6			39.3	39.6	877	878	860			
2/28/2006	180	0	180 CL	32	39.8	41.4	42.8			41.3	41.4	879	903	918			Tines wet
2/28/2006	240	0	240 CL	0	35.5	37.0	36.5			36.3	36.5	811	836	827			Auger pull chord on engine broke
2/28/2006	240	0	240 CL	12	34.2	35.1	33.5			34.3	34.2	789	806	778			
2/28/2006	240	0	240 CL	23	42.4	39.5	39.4			40.4	39.5	914	875	873			
2/28/2006	240	0	240 CL	29	38.2	37.5	38.5			38.1	38.2	854	843	859			Wet
2/28/2006	300	0	300 CL	0	36.3	38.6	37.3			37.4	37.3	824	861	840			
2/28/2006	300	0	300 CL	12	40.0	40.3	39.8			40.0	40.0	883	887	880			

Table B-11 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the winter IOP4.

Date	Station			Depth	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	(Using all readings)	Median	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	
				(in.)	(%)	(%)	(%)	(%)	(%)			(mV)	(mV)	(mV)	(mV)	(mV)	COMMENTS
2/28/2006	300	0	300 CL	23	37.9	38.4	38.7			38.3	38.4	850	858	862			Standing water
2/28/2006	300	0	300 CL	29	39.8	39.9	41.6			40.4	39.9	880	881	906			
2/28/2006	300	10	300 10 N	0	42.4	41.6	40.8			41.6	41.6	917	906	895			
2/28/2006	300	10	300 10 N	12	35.1	33.1	35.6			34.6	35.1	806	771	814			
2/28/2006	300	10	300 10 N	25	39.6	41.1	41.0			40.6	41.0	877	900	899			
2/28/2006	300	10	300 10 N	32	37.8	40.8	40.3			39.6	40.3	848	895	887			Water in bottom of hole
2/28/2006	300	10	300 10 S	0	39.9	40.8	39.3			40.0	39.9	882	896	872			
2/28/2006	300	10	300 10 S	14	34.9	38.5	37.2			36.9	37.2	802	860	838			
2/28/2006	300	10	300 10 S	24	40.2	39.6	40.0			39.9	40.0	886	877	883			Water coming in bottom of hole
2/28/2006	300	10	300 10 S														
2/28/2006	360	0	360 CL	0	42.5	40.2	40.9			41.2	40.9	915	887	897			
2/28/2006	360	0	360 CL	12	36.4	37.5	39.9			37.9	37.5	826	843	882			
2/28/2006	360	0	360 CL	24	39.9	40.2	39.7			39.9	39.9	871	886	878			Water coming into hole
2/28/2006	360	0	360 CL	30	40.9	40.4	42.6			41.3	40.9	897	889	916			Water in hole

Table B-11 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the winter IOP4.

Date	Station			Depth	Read-ing 1	Read-ing 2	Read-ing 3	Read-ing 4	Read-ing 5	(Using all read-ings)	Median	Read-ing 1	Read-ing 2	Read-ing 3	Read-ing 4	Read-ing 5	
				(in.)	(%)	(%)	(%)	(%)	(%)			(mV)	(mV)	(mV)	(mV)	(mV)	COMMENTS
2/28/2006	420	0	420 CL	0	40.3	40.5	40.7			40.5	40.5	887	891	894			
2/28/2006	420	0	420 CL	12	34.3	32.6	35.5			34.1	34.3	792	761	812			
2/28/2006	420	0	420 CL	24	32.0	33.8	34.7			33.5	33.8	751	782	800			
2/28/2006	420	0	420 CL	29	36.2	36.8	37.3			36.8	36.8	824	833	840			
2/28/2006	480	0	480 CL	0	41.4	39.5	40.5			40.5	40.5	904	874	891			
2/28/2006	480	0	480 CL	12	32.8	35.3	35.8			34.6	35.3	765	809	816			
2/28/2006	480	0	480 CL	24	39.4	39.3	40.4			39.7	39.4	874	871	889			
2/28/2006	480	0	480 CL	32	38.4	37.0	37.7			37.7	37.7	857	835	846			
2/28/2006	540	0	540 CL	0	41.1	38.8	39.8			39.9	39.8	901	865	880			
2/28/2006	540	0	540 CL	12	35.3	31.6	35.1	40.3	34.3	35.3	35.1	808	744	805	888	792	
2/28/2006	540	0	540 CL	24	39.0	38.4	38.6			38.7	38.6	866	858	861			Water accumulating in hole
2/28/2006	540	0	540 CL	31	41.2	39.6	40.4			40.4	40.4	901	877	889			Water in bottom of hole, very soft at bottom of hole
2/28/2006	585	0	585 CL	0	40.2	39.5	40.4			40.0	40.2	886	875	890			
2/28/2006	585	0	585 CL	11	31.7	33.5	34.8			33.3	33.5	747	777	801			
2/28/2006	585	0	585 CL	24	31.8	39.8	39.5	38.2		37.3	38.9	748	879	875	855		
2/28/2006	585	0	585 CL	30	37.5	37.3	38.5			37.8	37.5	843	841	859			
2/28/2006	600	10	600 10 N	0	41.6	42.5	42.2			42.1	42.2	906	915	912			
2/28/2006	600	10	600 10 N	11	32.1	33.8	33.3			33.1	33.3	754	783	774			
2/28/2006	600	10	600 10 N	24	38.6	38.2	40.3			39.0	38.6	860	854	887			
2/28/2006	600	10	600 10 N	32	37.0	38.8	38.3			38.0	38.3	835	864	856			
2/28/2006	600	0	600 CL	0	41.3	41.8	41.3			41.5	41.3	903	908	902			

Table B-11 (cont'd). Volumetric soil moisture measurements made at the North Vernon Airport RAS during the winter IOP4.

Date	Statio n			Dept h	Read-ing 1	Read-ing 2	Read-ing 3	Read-ing 4	Read-ing 5	(Usin g all read-ings)	Median	Read-ing 1	Read-ing 2	Read-ing 3	Read-ing 4	Read-ing 5	
				(in.)	(%)	(%)	(%)	(%)	(%)			(mV)	(mV)	(mV)	(mV)	(mV)	COMMENTS
2/28/2006	600	0	600 CL	13.5	38.1	36.0	35.4	33.2		35.7	35.7	852	819	811	773		
2/28/2006	600	0	600 CL	25	40.7	40.3	40.0			40.3	40.3	894	888	883			Sticky mud
2/28/2006	600	0	600 CL	33	40.9	43.6	41.6			42.0	41.6	897	926	906			
2/28/2006	600	10	600 10 S	0	40.5	38.4	40.0			39.6	40.0	891	858	883			
2/28/2006	600	10	600 10 S	11	32.3	30.7	23.4			28.8	30.7	758	730	587			
2/28/2006	600	10	600 10 S	25	39.8	40.0	41.6			40.5	40.0	880	883	905			
2/28/2006	600	10	600 10 S	30	39.4	38.3	42.6			40.1	39.4	873	856	916			

Table B-12. North Vernon Airport RAS DCP test results from winter IOP.

		Average CBR within 300 mm layers				
Date	Station	0–300	300–600	600–900	900–1,200	Source File
3/1/2006	0 m 10 m South - Manual comparison with Vertek	13	14	10		DCPARPT 0 10S.xls
3/1/2006	300 m 10 m North - Manual comparison with Vertek	3	4	5		DCPARPT 300 10N.xls
3/2/2006	585 m Centerline - Manual Repeat	5	3	9		DCPARPT 585 CL.xls
3/1/2006	600 m 10 m North	5	4	7		DCPARPT 600 10N.xls
3/1/2006	600 m 10 m South	7	4	6	3	DCPARPT 600 10S.xls
3/1/2006	600 m Centerline - Manual	4	3	7		DCPARPT 600 CL.xls
3/2/2006	600 m Centerline - Manual Repeat	4	3	5		DCPARPT 600 CL2.xls
3/1/2006	0 m 10 m North	17	8	5		ARPT 0 10N.txt
3/1/2006	0 m 10 m South	13	13	9		ARPT 0 10S.txt
3/1/2006	0 m Centerline	4	3	3		ARPT 0CL.txt
3/1/2006	120 m Centerline	4	5	5		ARPT 120CL.txt
3/1/2006	15 m Centerline	5	4	5		ARPT 15CL.txt
3/1/2006	180 m Centerline	4	3	4		ARPT 180CL.txt
3/1/2006	240 m Centerline	5	3	4		ARPT 240CL.txt
3/1/2006	300 m 10 m North	3	4	4		ARPT 300 10N.txt
3/1/2006	300 m 10 m South	4	3	13		ARPT 300 10S.txt
3/1/2006	300 m Centerline	3	5	5		ARPT 300CL.txt
3/1/2006	360 m Centerline	4	3	3		ARPT 360 CL.txt
3/1/2006	420 m Centerline	6	4	2		ARPT 420 CL.txt
3/1/2006	480 m Centerline	3	5	4		ARPT 480 CL.txt
3/1/2006	540 m Centerline	3	4	4		ARPT 540 CL.txt
3/1/2006	60 m Centerline	6	2	3		ARPT 60CL.txt
	Median of each layer	4	4	5		
	Maximum of each layer	17	14	13		
	Minimum of each layer	3	2	2		
	Standard Deviation of each layer	4	3	3		
	Median of all DCP points	4				
	Standard Deviation of all DCP points	3				

Appendix C: Ford Farm RAS Data

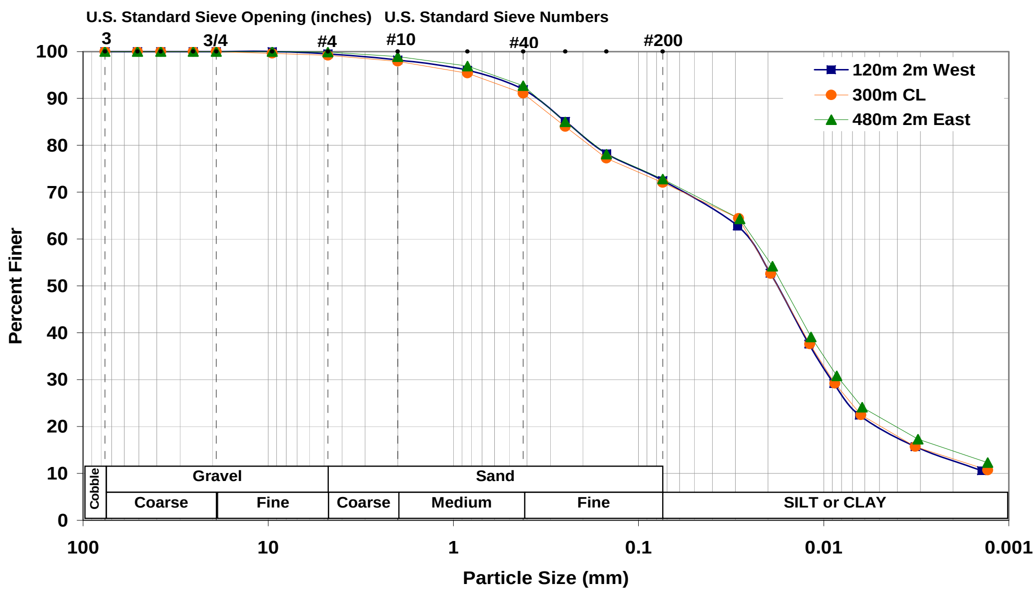


Figure C-1. Summary of soil classification for 0.6-m (2-ft) soil pits 25- to 152-mm (1- to 6-in.) below the surface.

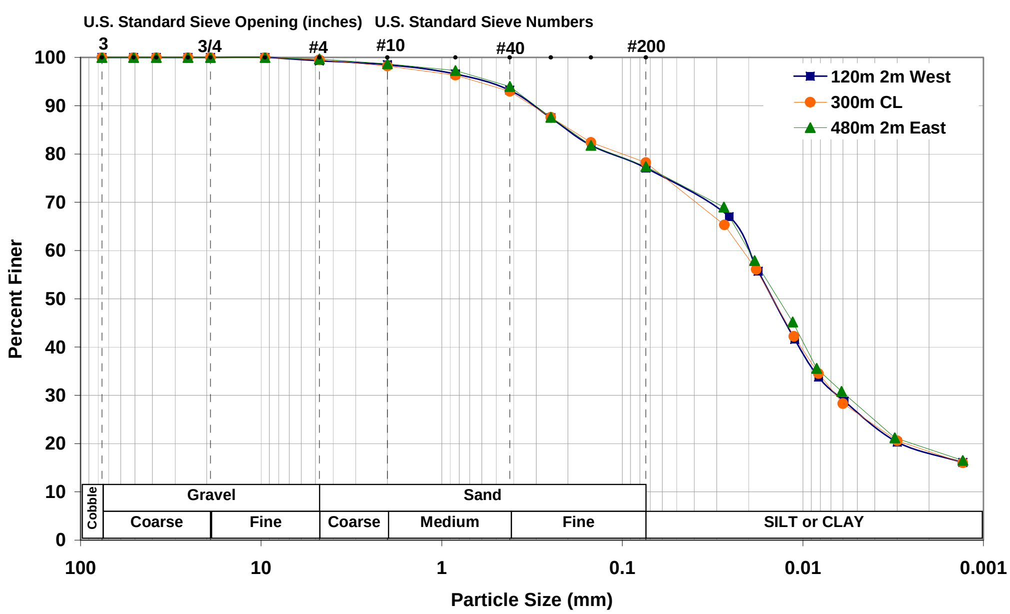


Figure C-2. Summary of soil classification for 0.6-m (2-ft) soil pits 305 mm (12 in.) below the surface.

Table C-1. Soil field measurements taken at the Ford Farm RAS sampling points during each IOP.

DCP = Dynamic Cone Penetrometer (Strength Profile)
Clegg = Clegg Hammer (Surface Strength)
Army Cone = Cone Index (Strength Profile)
Dor Cone (Surface Strength)
Dynamax = Soil Moisture (Surface and/or with depth)
S = Soil sample(s) taken
D = Density (Density using Troxler and/or Density using drive cylinder)
V = Vegetation Cover (images)

x indicates that a measurement was taken

	SPRING05								SUMMER05								FALL05								WINTER06							
Sampling points	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V	DCP	Clegg	Army Cone	Dor Cone	Dynamax	S	D	V
0m 10mW	x								x	x			x				x	x			x				x	x	x		x			
0m 10mE	x								x	x			x				x	x			x				x	x	x		x			
0m CL	x								x	x			x				x	x	x	x	x			x	x	x	x		x			x
15m CL	x								x	x			x				x	x	x	x	x			x	x	x	x		x			x
60m 10mW	x																	x			x											
60m 10mE	x																	x			x											
60m 2mW	x																															
60m CL	x								x	x			x				x	x	x	x	x			x	x	x	x		x			x
84m CL (Wet)					x	x		x																								
84m CL (Dry)					x	x		x																								
120m 10mW	x								x	x			x				x	x			x											
120m 10mE	x								x	x			x				x	x			x											
120m 2mW	x				x	x	x	x														x	x									
120m 2mE	x																															
120m CL	x		x						x	x			x				x	x	x	x	x			x	x	x	x		x			x
180m 10mW	x																	x			x											
180m 10mE	x																	x			x											
180m 2mW	x																															
180m 2mE	x				x	x	x	x																								
180m CL	x		x						x	x			x	x				x	x	x	x			x	x	x	x		x			x
240m 10mW	x		x															x			x											
240m 10mE	x		x															x			x											
240m 2mW	x		x																													
240m 2mE	x		x																													
240m CL	x		x						x	x			x					x	x	x	x			x	x	x	x		x			x
300m 10mW	x		x						x	x			x				x	x			x				x	x	x		x			
300m 10mE	x		x						x	x			x				x	x			x				x	x	x		x			
300m CL	x		x		x	x	x	x	x	x			x	x			x	x	x	x	x	x	x	x	x	x	x		x			x
360m 10mW	x		x														x				x											
360m 10mE	x		x														x				x											
360m 2mW	x		x																													
360m 2mE	x		x																													
360m CL	x		x						x	x			x				x	x	x	x	x			x	x	x	x		x			x
420m 10mW	x		x														x				x											
420m 10mE	x		x														x				x											
420m 2mW	x		x		x	x	x	x																								
420m 2mE	x		x																													
420m CL	x		x						x	x			x	x			x	x	x	x	x			x	x	x	x		x			x
480m 10mW	x		x						x				x				x	x			x											
480m 10mE			x						x	x			x				x	x			x											
480m 2mW	x		x																													
480m 2mE	x		x		x	x	x	x														x	x									
480m CL	x		x						x	x			x	x			x	x	x	x	x			x	x	x	x		x			x
540m 10mW	x																															
540m 10mE	x		x																													
540m 2mE	x		x																													
540m CL	x		x						x	x			x				x	x	x	x	x			x	x	x	x		x			x
585mCL	x		x						x	x			x				x	x	x	x	x			x	x	x	x		x			x
600m 10mW	x		x						x	x			x				x	x			x				x	x	x		x			
600m 10mE	x		x						x	x			x				x	x			x				x	x	x		x			
600m CL	x		x						x	x			x				x	x	x	x	x			x	x	x	x		x			x

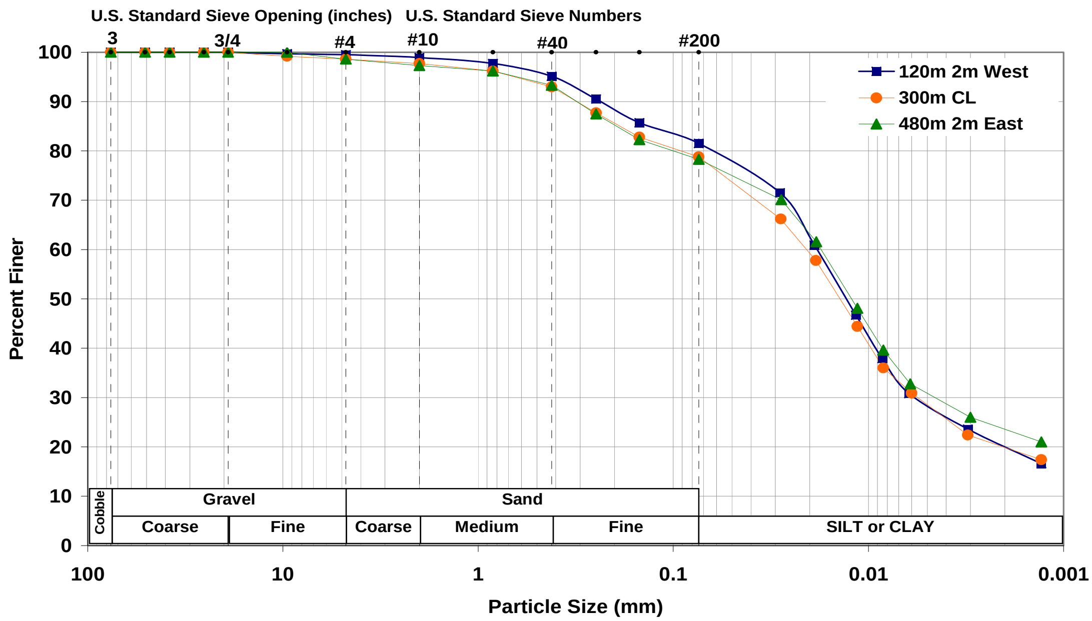


Figure C-3. Summary of soil classification for 0.6-m (2-ft) soil pits 610 mm (24 in.) below the surface.

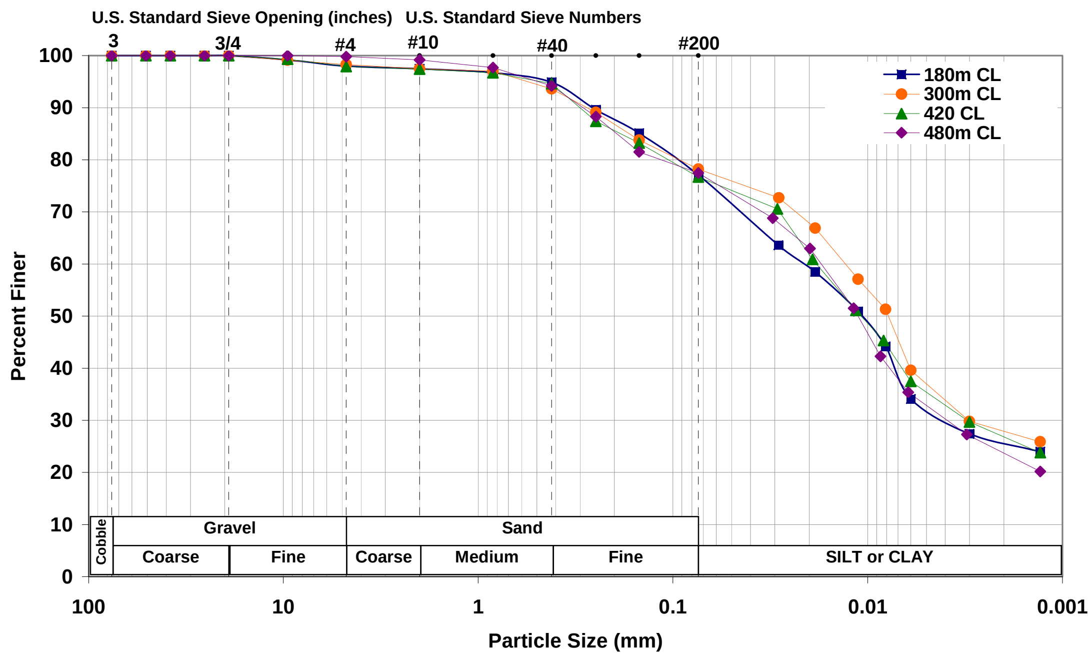


Figure C-4. Summary of soil classification for 0.6-m (2-ft) soil pits 305- to 660-mm (12- to 24-in.) below the surface.

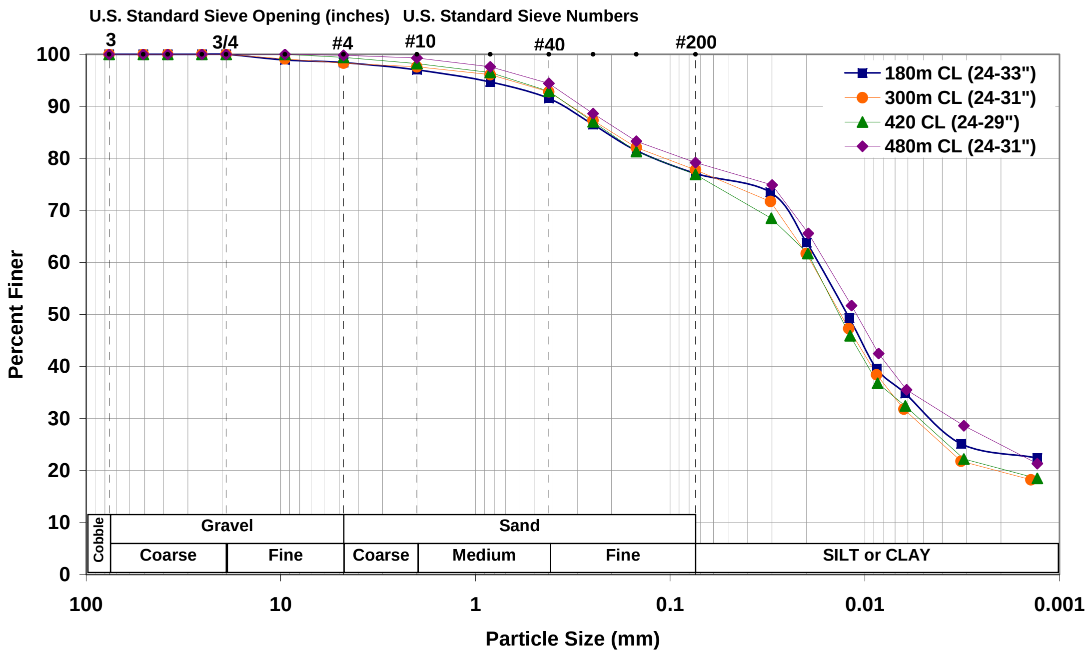


Figure C-5. Summary of soil classification for 0.6-m (2-ft) soil pits 610- to 890-mm (24- to 33-in.) below the surface.

Table C-2. Volumetric soil moisture measurements made at the Ford Farm RAS during the spring IOP.

Date	Station	Depth	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5	Median (using all readings)
		(in.)	(%)	(%)	(%)	(%)	(%)	
4/20/2005	Dry area	0	26.8	26.8	27.5			26.8
4/20/2005	Dry area	3	31.2	29.8	30.8	29.0		30.3
4/20/2005	Dry area	6	30.7	30.8	32.0	30.1		30.8
4/20/2005	Dry area	12	37.1	36.0	35.5	38.3		36.6
4/20/2005	Wet area	0	32.9	30.7	31.3	29.4		31.0
4/20/2005	Wet area	3	32.8	36.0	32.2	35.2		34.0
4/20/2005	Wet area	6	30.4	30.6	29.4	29.7		30.1
4/20/2005	Wet area	12	36.4	33.5	37.5	36.5		36.5
4/20/2005	480 2 E	0	24.9	25.0	26.9	24.3		25.0
4/20/2005	480 2 E	3	28.1	29.8	27.7			28.1
4/20/2005	480 2 E	6	31.9	31.2	30.1			31.2
4/20/2005	480 2 E	12	36.3	36.8	33.5	34.3		35.3
4/20/2005	480 2 E	18	35.9	40.2	36.5	38.9		37.7
4/20/2005	480 2 E	24	38.8	39.4	41.2	39.3		39.4
4/20/2005	300 CL	0	26.6	23.4	22.5	23.1		23.3
4/20/2005	300 CL	3	28.5	26.4	29.4	26.7		27.6
4/20/2005	300 CL	6	32.2	29.6	31.1	31.7		31.4
4/20/2005	300 CL	12	38.6	37.3	34.9	37.8		37.6
4/20/2005	300 CL	18	38.1	38.9	38.8			38.8
4/20/2005	300 CL	24	37.1	40.2	39.0	40.8		39.6
4/20/2005	240 2 W	0	29.9	32.2	29.0			29.9
4/20/2005	240 2 W	3	31.4	28.8	30.7			30.7
4/20/2005	240 2 W	6	31.0	31.9	30.1			31.0
4/20/2005	240 2 W	12	34.3	36.0	35.1			35.1
4/20/2005	180 2 E	0	26.9	24.4	25.4	25.7		25.6
4/20/2005	180 2 E	3	26.2	23.4	23.2	25.1		24.3
4/20/2005	180 2 E	6	28.3	28.1	28.7	26.4	29.6	28.3
4/20/2005	180 2 E	12	34.4	37.7	35.8	37.0		36.4
4/20/2005	120 2 W	0	24.9	26.1	25.1			25.1
4/20/2005	120 2 W	3	27.1	29.7	32.5	26.6		28.4
4/20/2005	120 2 W	6	30.1	32.5	34.0	32.4		32.5
4/20/2005	120 2 W	12	33.8	36.9	35.8	34.0		34.9
4/20/2005	120 2 W	18	36.5	36.9	35.0			36.5
4/20/2005	120 2 W	24	39.8	41.4	35.8	37.9		38.9

Table C-3. Volumetric soil moisture measurements made at Ford Farm RAS during the summer IOP.

Date	Station	Depth (in.)	Median (%)	Comments
8/3/2005	0 CL	0	9.3	Heavy vegetation
8/3/2005	0 CL	12	17.4	
8/3/2005	0 CL	24	22.2	
8/3/2005	0 CL	32	26.7	
8/4/2005	0 10 W	0	11.0	
8/4/2005	0 10 W	12	22.3	
8/4/2005	0 10 W	24	22.9	
8/4/2005	0 10 W	30	25.8	
8/4/2005	0 10 E	0	8.9	
8/4/2005	0 10 E	12	17.6	
8/4/2005	0 10 E	24	23.3	
8/4/2005	0 10 E	30	27.6	
8/3/2005	15 CL	0	15.9	Auger cuttings are blocky, dry pieces of clay material; break w/little pressure
8/3/2005	15 CL	12	13.8	
8/3/2005	15 CL	24	22.1	
8/3/2005	15 CL	30	23.5	
8/3/2005	60 CL	0		Missing reading
8/3/2005	60 CL	12	19.9	
8/3/2005	60 CL	25	22.2	
8/3/2005	60 CL	34	29.2	
8/3/2005	120 CL	0	12.3	Soil sticking in between tines of HH2 probe
8/3/2005	120 CL	12	17.8	
8/3/2005	120 CL	24	24.5	
8/3/2005	120 CL	31	25.6	
8/4/2005	120 10 E	0	13.2	
8/4/2005	120 10 E	11	19.2	
8/4/2005	120 10 E	24	24.1	
8/4/2005	120 10 E	30	26.8	
8/4/2005	120 10 W	0	12.2	
8/4/2005	120 10 W	12	20.4	
8/4/2005	120 10 W	24	24.5	
8/4/2005	120 10 W	32	25.9	
8/3/2005	180 CL	0	17.8	
8/3/2005	180 CL	12	26.0	
8/3/2005	180 CL	23.5	25.7	HH2 displayed 'underrange'
8/3/2005	180 CL	33	26.7	HH2 displayed 'underrange'

Table C-3 (cont'd). Volumetric soil moisture measurements made at Ford Farm RAS during the summer IOP.

Date	Station	Depth (in.)	Median (%)	Comments
8/3/2005	240 CL	0	15.5	
8/3/2005	240 CL	13	24.9	
8/3/2005	240 CL	25	26.5	
8/3/2005	240 CL	31	28.1	Soil sticking to probe tines
8/3/2005	300 CL	0	15.7	Could see pit location from April 2005
8/3/2005	300 CL	12	26.4	
8/3/2005	300 CL	24	30.5	
8/3/2005	300 CL	33	31.0	
8/4/2005	300 10 W	0	10.3	
8/4/2005	300 10 W	12	15.3	
8/4/2005	300 10 W	24	21.7	
8/4/2005	300 10 W	30	23.2	
8/4/2005	300 10 E	0	17.7	
8/4/2005	300 10 E	12	26.4	
8/4/2005	300 10 E	23	26.8	
8/4/2005	300 10 E	31	28.0	
8/3/2005	360 CL	0	12.3	
8/3/2005	360 CL	12	21.1	
8/3/2005	360 CL	23	23.0	
8/3/2005	360 CL	31	23.5	
8/3/2005	420 CL	0	17.3	Surface firm, hard to push HH2 probe
8/3/2005	420 CL	12	17.7	
8/3/2005	420 CL	24	22.7	
8/3/2005	420 CL	29	25.0	Soil sticking to probe tines
8/3/2005	480 CL	0	14.8	
8/3/2005	480 CL	12	16.6	
8/3/2005	480 CL	24	23.9	
8/3/2005	480 CL	31	26.4	HH2 displayed 'underrange'
8/4/2005	480 10 E	0	18.1	
8/4/2005	480 10 E	12	21.7	
8/4/2005	480 10 E	24	25.8	
8/4/2005	480 10 E	31	25.0	
8/4/2005	480 10 W	0	13.3	MC taken near Clegg location
8/4/2005	480 10 W	12	21.7	
8/4/2005	480 10 W	23	22.7	
8/4/2005	480 10 W	29.5	25.6	
8/3/2005	540 CL	0	16.3	

Table C-3 (cont'd). Volumetric soil moisture measurements made at Ford Farm RAS during the summer IOP.

Date	Station	Depth (in.)	Median (%)	Comments
8/3/2005	540 CL	12	18.9	
8/3/2005	540 CL	22	25.1	
8/3/2005	540 CL	32	28.0	
8/3/2005	585 CL	0	15.0	Very difficult to auger; 3rd hole was successful
8/3/2005	585 CL	14	18.2	
8/3/2005	585 CL	23	24.3	Soil sticking to HH2 probe tines
8/3/2005	585 CL	33	20.3	
8/4/2005	600 10 W	0	9.6	Vegetation/weeds
8/4/2005	600 10 W	12	23.7	
8/4/2005	600 10 W	23	26.7	
8/4/2005	600 10 W	30	28.0	
8/4/2005	600 CL	0	17.6	WX conditions sunny, clear, wind calm, sky clear, warm
8/4/2005	600 CL	12	27.1	
8/4/2005	600 CL	24	30.4	
8/4/2005	600 CL	32	26.3	
8/4/2005	600 10 E	0	13.7	
8/4/2005	600 10 E	13	25.4	
8/4/2005	600 10 E	26	30.6	
8/4/2005	600 10 E	30	29.0	

Table C-4. Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Read-ing 1	Read-ing 1	Read-ing 2	Read-ing 2	Read-ing 3	Read-ing 3	Read-ing 4	Read-ing 4	Read-ing 5	Read-ing 5	Read-ing 6	Read-ing 6	Read-ing 7	Read-ing 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
10/30/2005	0 10 E	0	22.9	574	24.0	600	25.4	627									24.0
10/30/2005	0 10 E	6	27.0	660	29.8	713	28.7	694									28.7
10/30/2005	0 10 E	12	30.8	731	28.4	690	25.8	635									28.4
11/1/2005	0 10 E	23	26.7	654	30.0	717	29.9	715									29.9
11/1/2005	0 10 E	28	30.7	729	29.5	708	34.6	798									30.7
10/31/2005	0 10 W	0	24.3	604	29.2	702	24.7	612	27.2	665							26.0
10/31/2005	0 10 W	6	29.2	703	27.5	669	28.1	683									28.1
10/31/2005	0 10 W	12	31.1	736	30.4	724	32.6	762									31.1
10/31/2005	0 10 W	0	27.0	661	31.3	740	29.5	708	24.3	604							28.3
10/31/2005	0 10 W	23	31.0	735	28.5	691	32.5	760	31.0	735							31.0
10/31/2005	0 10 W	29	26.4	648	30.4	724	29.6	710									29.6
10/30/2005	60 10 E	0	24.2	602	24.3	604	25.5	630									24.3
10/30/2005	60 10 E	6	29.4	706	27.2	665	31.2	738									29.4
10/30/2005	60 10 E	12	28.6	693	28.9	699	28.1	682									28.6
10/31/2005	60 10 W	0	21.6	546	23.9	598	19.3	494	15.8	406	16.2	417	18.4	472			18.9

Table C-4 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Read-ing 1	Read-ing 1	Read-ing 2	Read-ing 2	Read-ing 3	Read-ing 3	Read-ing 4	Read-ing 4	Read-ing 5	Read-ing 5	Read-ing 6	Read-ing 6	Read-ing 7	Read-ing 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
10/31/2005	60 10 W	6	29.8	713	32.1	754	26.4	648									29.8
10/31/2005	60 10 W	12	32.5	761	32.6	762	30.7	729									32.5
10/30/2005	120 10 E	0	17.9	461	24.4	607	30.2	720									24.4
10/30/2005	120 10 E	6	30.4	723	31.1	736	30.2	721									30.4
10/30/2005	120 10 E	12	32.2	755	30.0	717	32.1	754									32.1
11/1/2005	120 10 E	24	35.5	811	35.4	810	36.1	821									35.5
11/1/2005	120 10 E	29	36.6	829	35.3	809	37.1	838									36.6
10/30/2005	120 CL	0	21.2	536	17.8	459	18.3	469									18.3
10/30/2005	120 CL	6	23.5	588	24.0	598	28.2	686									24.0
10/30/2005	120 CL	12	26.0	639	31.1	737	28.1	684									28.1
11/1/2005	120 CL	23	27.2	664	26.4	649	31.6	746	32.3	757							29.4
11/1/2005	120 CL	28	22.3	561	26.5	650	23.6	590	26.0	641							24.8
10/31/2005	120 10 W	0	17.3	445	16.8	433	15.9	411									16.8
10/31/2005	120 10 W	6	26.4	647	25.8	636	26.3	647									26.3
10/31/2005	120 10 W	12	33.0	769	33.0	770	30.8	732									33.0
11/1/2005	120 10 W	24	32.8	766	32.8	766	32.3	758									32.8
11/1/2005	120 10 W	29	33.0	769	34.1	789	34.7	800									34.1

Table C-4 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Reading 1	Reading 1	Reading 2	Reading 2	Reading 3	Reading 3	Reading 4	Reading 4	Reading 5	Reading 5	Reading 6	Reading 6	Reading 7	Reading 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
10/30/2005	180 10 E	0	24.1	601	24.2	602	23.3	584									24.1
10/30/2005	180 10 E	6	26.6	653	26.3	646	27.5	671									26.6
10/30/2005	180 10 E	12	32.3	756	32.4	758	32.4	758									32.4
10/30/2005	180 CL	0	26.4	648	20.7	524	23.9	597									23.9
10/30/2005	180 CL	6	27.8	677	24.8	615	26.6	652									26.6
10/30/2005	180 CL	12	30.1	719	30.9	733	30.7	729									30.7
11/1/2005	180 CL	23	31.3	740	32.5	761	33.4	775	33.4	777							33.0
11/1/2005	180 CL	31	26.9	659	29.7	713	33.2	772	31.2	739							30.5
10/31/2005	180 10 W	0	19.6	501	19.5	499	17.8	457									19.5
10/31/2005	180 10 W	6	23.5	589	25.5	630	25.2	624									25.2
10/31/2005	180 10 W	12	31.4	742	34.5	796	33.5	778									33.5
10/30/2005	240 10 E	0	19.4	497	19.2	492	20.7	526									19.4
10/30/2005	240 10 E	6	28.7	695	25.3	625	26.8	657									26.8
10/30/2005	240 10 E	12	30.5	727	31.5	743	30.4	724									30.5
10/30/2005	240 CL	0	23.6	590	23.6	591	24.6	611									23.6
10/30/2005	240 CL	6	27.1	663	28.7	694	26.8	657									27.1
10/30/2005	240 CL	12	31.5	743	28.2	685	28.4	689									28.4

Table C-4 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Read-ing 1	Read-ing 1	Read-ing 2	Read-ing 2	Read-ing 3	Read-ing 3	Read-ing 4	Read-ing 4	Read-ing 5	Read-ing 5	Read-ing 6	Read-ing 6	Read-ing 7	Read-ing 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
11/1/2005	240 CL	23	28.5	692	31.8	749	29.9	716									29.9
11/1/2005	240 CL	29	23.8	594	31.3	739	31.3	739	29.7	712							30.5
10/31/2005	240 10 W	0	19.1	490	16.7	431	17.2	441	14.9	384							17.0
10/31/2005	240 10 W	6	28.0	681	30.0	717	29.4	707									29.4
10/31/2005	240 10 W	12	30.5	726	33.1	771	30.8	731									30.8
10/30/2005	300 10 E	0	28.4	689	26.2	644	26.3	645									26.3
10/30/2005	300 10 E	6	27.6	672	26.7	654	27.9	670									27.6
10/30/2005	300 10 E	12	33.1	771	34.1	789	32.0	752									33.1
11/1/2005	300 10 E	22	31.1	789	33.9	785	35.5	812	34.8	800							34.4
11/1/2005	300 10 E	27	33.8	784	37.0	835	32.2	756	34.1	788							34.0
11/1/2005	300 CL	23	30.6	727	35.9	818	29.7	712	33.6	779							32.1
11/1/2005	300 CL	27	28.6	693	33.3	775	27.1	663	28.7	694							28.7
10/31/2005	300 10 W	0	16.0	412	23.6	590	24.3	606	15.0	383	14.5	375	23.4	586	17.8	458	17.8
10/31/2005	300 10 W	6	27.1	662	28.4	689	27.0	660									27.1
10/31/2005	300 10 W	12	30.0	717	31.1	736	26.9	659	28.3	687							29.2
11/1/2005	300 10 W	22	25.3	626	23.3	585	27.1	662	30.3	722	28.3	687					27.1
11/1/2005	300 10 W	28	25.5	629	20.8	528	22.8	572	25.5	629							24.2

Table C-4 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Reading 1	Reading 1	Reading 2	Reading 2	Reading 3	Reading 3	Reading 4	Reading 4	Reading 5	Reading 5	Reading 6	Reading 6	Reading 7	Reading 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
10/30/2005	360 10 E	0	18.0	463	24.6	610	19.8	505									19.8
10/30/2005	360 10 E	6	26.8	656	27.3	667	27.6	673									27.3
10/30/2005	360 10 E	12	33.7	781	30.9	733	32.9	767									32.9
11/1/2005	360 CL	24	27.5	670	26.2	644	27.3	667									27.3
11/1/2005	360 CL	29	21.7	547	24.4	606	27.3	666	25.9	637							25.2
10/31/2005	360 10 W	0	21.4	541	19.4	496	23.5	589									21.4
10/31/2005	360 10 W	6	26.3	646	27.0	661	27.9	679									27.0
10/31/2005	360 10 W	12	31.0	734	33.1	771	32.8	767									32.8
10/30/2005	420 10 E	0	22.8	573	19.9	507	23.2	583									22.8
10/30/2005	420 10 E	6	30.0	717	31.2	738	24.7	614									30.0
10/30/2005	420 10 E	12	20.1	683	33.1	771	30.8	731									30.8
10/30/2005	420 CL	0	17.3	446	18.6	434	21.9	533									18.6
10/30/2005	420 CL	6	27.2	665	28.9	697	25.1	621									27.2
10/30/2005	420 CL	12	29.2	704	30.0	716	25.7	634									29.2
11/1/2005	420 CL	21	24.3	605	24.1	602	25.0	619									24.3
11/1/2005	420 CL	28	23.1	579	24.9	618	25.8	636	29.4	707							25.4

Table C-4 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Read-ing 1	Read-ing 1	Read-ing 2	Read-ing 2	Read-ing 3	Read-ing 3	Read-ing 4	Read-ing 4	Read-ing 5	Read-ing 5	Read-ing 6	Read-ing 6	Read-ing 7	Read-ing 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
10/31/2005	420 10 W	0	14.0	362	22.5	565	15.8	408	18.2	468	18.4	473					18.2
10/31/2005	420 10 W	6	27.8	677	27.5	671	27.2	664									27.5
10/31/2005	420 10 W	12	32.4	758	33.5	778	34.1	789									33.5
10/31/2005	480 CL	0	21.2	537	24.7	612	22.8	573									22.8
10/31/2005	480 CL	6	31.1	736	29.7	712	29.3	705									29.7
10/31/2005	480 CL	12	29.0	700	31.0	734	32.0	755									31.0
11/1/2005	480 CL	22	28.2	685	24.9	617	31.0	734	31.0	735							29.6
11/1/2005	480 CL	28	25.2	624	27.4	669	28.0	680	27.1	663							27.3
10/31/2005	480 10 E	0	18.3	470	18.1	466	17.5	451									18.1
10/31/2005	480 10 E	6	29.1	701	29.0	700	26.1	642	28.2	635							28.6
10/31/2005	480 10 E	12	30.7	729	31.6	744	30.2	720									30.7
11/1/2005	480 10 E	22	29.6	709	30.1	719	30.4	724									30.1
11/1/2005	480 10 E	27	28.7	695	29.7	712	31.7	746									29.7
10/31/2005	480 10 W	0	19.1	488	21.4	540	18.8	482									19.1
10/31/2005	480 10 W	6	28.7	694	27.5	671	29.4	706									28.7
10/31/2005	480 10 W	12	32.5	760	30.0	717	31.9	750									31.9
11/1/2005	480 10 W	22	30.2	720	28.4	689	31.0	734									30.2
11/1/2005	480 10 W	28	32.9	768	31.6	745	33.6	779									32.9

Table C-4 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Read-ing 1	Read-ing 1	Read-ing 2	Read-ing 2	Read-ing 3	Read-ing 3	Read-ing 4	Read-ing 4	Read-ing 5	Read-ing 5	Read-ing 6	Read-ing 6	Read-ing 7	Read-ing 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
10/31/2005	540 CL	0	18.8	482	19.9	508	19.9	507									19.9
10/31/2005	540 CL	6	25.7	634	31.2	737	30.3	723									30.3
10/31/2005	540 CL	12	34.5	796	32.7	765	33.4	776									33.4
11/1/2005	540 CL	22	37.2	838	37.0	836	37.2	838									37.2
11/1/2005	540 CL	28	31.2	738	35.6	813	36.0	820	37.6	845							35.8
10/31/2005	585 CL	0	16.5	424	15.1	389	16.3	420									16.3
10/31/2005	585 CL	6	27.2	663	29.3	704	29.3	703									29.3
10/31/2005	585 CL	12	32.2	756	31.3	740	32.6	762									32.2
11/1/2005	585 CL	24	28.0	680	25.9	638	27.2	665	31.1	736	27.5	671					27.5
11/1/2005	585 CL	28	20.1	511	26.0	640	25.5	630	29.4	706							25.8
10/31/2005	600 CL	0	18.1	466	23.3	585	22.3	562									22.3
10/31/2005	600 CL	6	28.3	687	29.0	700	29.4	706									29.0
10/31/2005	600 CL	12	29.0	699	29.9	714	27.9	680									29.0
11/1/2005	600 CL	22	23.2	582	30.5	725	31.6	744	28.3	686							29.4
11/1/2005	600 CL	28	21.7	548	22.4	564	22.8	574									22.4
10/31/2005	600 10 W	0	13.4	344	18.2	467	18.6	477	20.3	517							18.4
10/31/2005	600 10 W	6	29.5	707	28.4	690	27.9	678									28.4
10/31/2005	600 10 W	12	32.2	755	33.7	782	32.2	755									32.2

Table C-4 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Reading 1	Reading 1	Reading 2	Reading 2	Reading 3	Reading 3	Reading 4	Reading 4	Reading 5	Reading 5	Reading 6	Reading 6	Reading 7	Reading 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
11/1/2005	600 10 W	22	35.5	812	36.0	820	35.6	814									35.6
11/1/2005	600 10 W	27	34.6	797	36.4	826	35.2	806									35.2
10/31/2005	600 10 E	0	17.3	444	17.6	453	15.1	389									17.3
10/31/2005	600 10 E	6	28.0	681	26.5	651	24.6	612									26.5
10/31/2005	600 10 E	12	31.6	745	31.0	735	30.8	730									31.0
11/1/2005	600 10 E	22	34.3	791	32.6	762	32.7	764									32.7
11/1/2005	600 10 E	28	32.7	764	34.8	801	32.1	754									32.7
10/30/2005	60 CL	0	17.9	461	17.9	460	21.1	534	17.9	459							17.9
10/30/2005	60 CL	6	27.6	673	28.0	680	27.9	680									27.9
10/30/2005	60 CL	12	34.2	790	32.0	752	33.1	770									33.1
10/31/2005	60 CL	0	16.1	416	18.1	465	22.7	571	11.0	298							17.1
10/31/2005	60 CL	6	25.8	635	24.6	612	24.7	613									24.7
10/31/2005	60 CL	12	19.1	489	30.2	720	25.2	624	23.6	590							24.4
10/31/2005	60 CL	24	22.0	556	23.9	596	24.7	614									23.9
10/31/2005	60 CL	28	24.2	603	24.5	608	24.4	607									24.4
10/30/2005	0 CL	0	22.3	562	32.5	760	23.8	595	20.0	510	31.0	735	24.9	618	23.2	581	23.8
		6	28.7	694	28.6	693	28.7	694									28.7
		12	35.0	804	36.5	828	32.6	762									35.0
10/31/2005	0 CL	0	30.0	717	19.4	495	30.0	717									30.0
		6	24.9	617	23.9	597	23.0	578									23.9

Table C-4 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Read-ing 1	Read-ing 1	Read-ing 2	Read-ing 2	Read-ing 3	Read-ing 3	Read-ing 4	Read-ing 4	Read-ing 5	Read-ing 5	Read-ing 6	Read-ing 6	Read-ing 7	Read-ing 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
		12	26.5	650	16.3	421	24.9	617	28.7	695							25.7
		23	25.4	628	26.5	649	30.0	717									26.5
		29	28.7	694	28.3	686	32.2	756									28.7
10/30/2005	15 CL	0	25.8	637	21.7	547	21.6	546									21.7
		6	27.5	671	28.5	691	28.7	694									28.5
		12	29.8	713	32.5	761	30.7	729									30.7
10/31/2005	15 CL	0	20.2	514	17.5	451	19.2	492	15.5	399							18.4
		6	24.1	601	26.0	641	26.5	650									26.0
		12	28.0	680	22.8	573	24.8	615									24.8
		24	28.6	692	28.9	698	28.9	698									28.9
		28	24.6	610	30.5	726	31.5	744	29.7	712							30.1
10/30/2005	120 CL	0	21.8	549	17.3	446	17.9	461									17.9
		6	30.2	721	29.1	701	29.2	703									29.2
		12	33.7	78	32.7	76	32.7	76									32.7
10/30/2005	180 CL	0	7.3	221	25.7	635	17.4	448	25.0	619	19.9	508					19.9
		6	29.3	704	26.8	656	26.3	645									26.8
		12	33.0	770	33.4	776	37.4	841									33.4

Table C-4 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the fall IOP.

Date		Depth	Reading 1	Reading 1	Reading 2	Reading 2	Reading 3	Reading 3	Reading 4	Reading 4	Reading 5	Reading 5	Reading 6	Reading 6	Reading 7	Reading 7	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
10/30/2005	240 CL	0	17.1	441	17.3	446	14.6	376	15.2	391							16.2
		6	27.5	670	27.9	680	25.9	639									27.5
		12	28.9	697	29.6	710	29.1	700									29.1
10/30/2005	300 CL	0	15.9	409	18.2	467	18.4	474									18.2
		6	27.4	667	27.7	675	27.4	669									27.4
		12	33.2	772	31.8	748	33.1	771									33.1
10/30/2005	360 CL	0	16.7	430	21.8	549	19.1	489	18.3	469							18.7
		6	26.0	640	27.0	661	28.3	687									27.0
		12	31.3	739	29.1	700	27.9	679	32.1	753							30.2

Table C-5. Volumetric soil moisture measurements made at the Ford Farm RAS during the winter IOP.

Date		Depth	Reading 1	Reading 1	Reading 2	Reading 2	Reading 3	Reading 3	Reading 4	Reading 4	Reading 5	Reading 5	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
3/1/2006	0 CL	0	30.4	724	30.7	730	29.5	709	–	–	–	–	30.4
3/1/2006	0 CL	12	27.5	670	32.2	755	34.2	790	35.4	810	–	–	33.2
3/1/2006	0 CL	23	36.4	826	35.8	817	30.5	725	37.0	835	–	–	36.1
3/1/2006	0 CL	30	39.8	880	39.0	867	37.2	838	–	–	–	–	39.0
3/1/2006	0 10 W	0	35.2	806	34.2	789	34.7	799	–	–	–	–	34.7
3/1/2006	0 10 W	11	34.5	795	34.6	798	34.6	797	–	–	–	–	34.6
3/1/2006	0 10 W	22	33.5	777	37.0	835	37.4	842	35.6	814	–	–	36.3
3/1/2006	0 10 W	30	35.8	817	39.1	868	38.6	860	37.5	843	–	–	38.1
3/1/2006	0 10 E	0	29.7	713	29.3	704	29.8	714	–	–	–	–	29.7
3/1/2006	0 10 E	11	31.3	739	34.9	802	29.8	714	34.9	802	–	–	33.1
3/1/2006	0 10 E	23	38.5	859	32.5	760	38.9	866	37.3	840	–	–	37.9
3/1/2006	0 10 E	31	35.7	815	29.8	713	34.0	786	38.8	863	–	–	34.9
3/1/2006	15 CL	0	30.5	725	31.2	737	35.7	814	34.5	795	–	–	32.9
3/1/2006	15 CL	12	34.5	795	33.2	773	35.5	811	–	–	–	–	34.5
3/1/2006	15 CL	24	40.4	890	37.1	837	36.0	820	37.7	846	–	–	37.4
3/1/2006	15 CL	33	39.5	876	40.5	890	41.5	904	–	–	–	–	40.5
3/1/2006	60 CL	0	31.6	745	30.7	729	33.4	776	–	–	–	–	31.6
3/1/2006	60 CL	12	35.4	810	36.4	826	34.7	799	–	–	–	–	35.4
3/1/2006	60 CL	24	36.9	834	35.9	819	36.7	830	–	–	–	–	36.7
3/1/2006	60 CL	30	37.8	848	34.7	799	34.5	796	38.8	864	–	–	36.3
3/1/2006	120 CL	0	33.5	778	28.1	683	31.5	742	33.6	779	–	–	32.5
3/1/2006	120 CL	14	32.1	753	34.7	800	36.7	831	37.4	841	–	–	35.7
3/1/2006	120 CL	24	29.9	715	34.7	799	36.1	821	32.8	766	–	–	33.8
3/1/2006	120 CL	30	32.8	766	33.7	782	34.2	790	–	–	–	–	33.7

Table C-5 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the winter IOP.

Date		Depth	Reading 1	Reading 1	Reading 2	Reading 2	Reading 3	Reading 3	Reading 4	Reading 4	Reading 5	Reading 5	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
3/1/2006	180 CL	0	37.9	843	34.2	790	33.3	775	–	–	–	–	34.2
3/1/2006	180 CL	11	31.4	741	34.3	793	34.0	787	31.2	737	–	–	32.7
3/1/2006	180 CL	24	31.4	741	38.8	863	36.6	829	35.6	813	–	–	36.1
3/1/2006	240 CL	0	34.5	795	33.7	781	36.2	824	35.4	810	–	–	35.0
3/1/2006	240 CL	12	36.0	819	34.3	791	33.5	778	31.8	748	33.4	776	33.5
3/1/2006	240 CL	24	36.4	826	33.4	776	33.8	786	37.7	847	–	–	35.1
3/1/2006	240 CL	30	37.1	838	35.6	813	38.6	861	37.9	850	–	–	37.5
3/1/2006	300 CL	0	31.0	734	32.5	760	32.6	762	–	–	–	–	32.5
3/1/2006	300 CL	12	37.9	850	36.1	822	37.6	846	–	–	–	–	37.6
3/1/2006	300 CL	23	38.0	851	38.6	861	39.9	882	–	–	–	–	38.6
3/1/2006	300 CL	30	38.7	863	36.7	830	38.4	858	–	–	–	–	38.4
3/1/2006	300 10 W	0	36.2	823	34.2	790	34.0	786	–	–	–	–	34.2
3/1/2006	300 10 W	13	37.7	846	36.3	825	38.8	864	–	–	–	–	37.7
3/1/2006	300 10 W	23	31.7	747	34.5	796	33.0	770	–	–	–	–	33.0
3/1/2006	300 10 W	29	31.8	748	34.0	787	33.3	774	–	–	–	–	33.3
3/1/2006	300 10 E	0	31.9	750	32.8	766	31.4	744	–	–	–	–	31.9
3/1/2006	300 10 E	12	34.2	789	35.4	810	33.1	772	–	–	–	–	34.2
3/1/2006	300 10 E	23	35.3	808	39.1	868	37.3	840	–	–	–	–	37.3
3/1/2006	300 10 E	31	36.8	832	36.7	831	39.7	878	–	–	–	–	36.8
3/1/2006	360 CL	0	30.9	733	31.9	751	28.7	693	–	–	–	–	30.9
3/1/2006	360 CL	11	35.4	809	37.9	850	35.2	806	–	–	–	–	35.4
3/1/2006	360 CL	23	33.8	784	34.1	788	32.8	766	–	–	–	–	33.8
3/1/2006	360 CL	30	30.3	723	30.9	733	33.8	782	–	–	–	–	30.9
3/1/2006	420 CL	0	31.8	749	28.8	696	32.5	761	32.8	765	–	–	32.2

Table C-5 (cont'd). Volumetric soil moisture measurements made at the Ford Farm RAS during the winter IOP.

Date		Depth	Reading 1	Reading 1	Reading 2	Reading 2	Reading 3	Reading 3	Reading 4	Reading 4	Reading 5	Reading 5	Median
		(in.)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)	(mV)	(%)
3/1/2006	420 CL	12	34.1	789	35.1	805	32.7	764	14.3	368	–	–	33.4
3/1/2006	420 CL	23	36.1	821	34.0	788	34.0	787	–	–	–	–	34.0
3/1/2006	420 CL	30	40.8	896	38.0	852	38.7	863	–	–	–	–	38.7
3/1/2006	480 CL	0	28.7	694	33.8	783	30.7	729	28.6	692	–	–	29.7
3/1/2006	480 CL	12	27.8	676	39.9	882	36.8	832	38.3	856	–	–	37.6
3/1/2006	480 CL	24	39.4	873	39.5	875	36.4	826	–	–	–	–	39.4
3/1/2006	480 CL	30	34.8	801	37.1	837	38.0	852	–	–	–	–	37.1
3/1/2006	540 CL	0	34.1	789	31.8	748	29.8	714	33.4	777	–	–	32.6
3/1/2006	540 CL	11	33.3	775	30.8	731	32.2	756	–	–	–	–	32.2
3/1/2006	540 CL	24	39.4	873	40.6	893	39.9	881	–	–	–	–	39.9
3/1/2006	540 CL	29	38.2	855	37.0	836	38.4	858	–	–	–	–	38.2
3/2/2006	585 CL	0	32.0	751	29.1	701	28.9	697	–	–	–	–	29.1
3/2/2006	585 CL	12	38.3	856	36.5	828	38.3	856	–	–	–	–	38.3
3/2/2006	585 CL	24	43.5	925	45.3	944	43.8	928	–	–	–	–	43.8
3/2/2006	585 CL	30	49.8	991	–	–	–	–	–	–	–	–	49.8
3/2/2006	600 10 W	0	29.8	714	27.6	673	24.9	617	29.1	701	–	–	28.4
3/2/2006	600 10 W	12	35.8	817	36.7	831	35.4	810	–	–	–	–	35.8
3/2/2006	600 10 W	24	40.5	891	40.7	893	42.6	917	–	–	–	–	40.7
3/2/2006	600 10 W	30	44.2	932	46.4	956	44.7	938	–	–	–	–	44.7
3/2/2006	600 CL	0	28.5	690	30.4	723	30.9	733	–	–	–	–	30.4
3/2/2006	600 CL	12	33.8	783	35.2	802	34.2	791	–	–	–	–	34.2
3/2/2006	600 CL	24	40.6	892	37.7	846	39.1	869	–	–	–	–	39.1
3/2/2006	600 CL	30	35.8	817	32.6	762	39.5	875	37.2	838	–	–	36.5
3/2/2006	600 10 E	0	30.5	725	31.3	739	31.9	750	–	–	–	–	31.3
3/2/2006	600 10 E	12	33.2	773	34.4	794	36.6	830	–	–	–	–	34.4
3/2/2006	600 10 E	22	38.2	854	38.0	851	37.0	836	–	–	–	–	38.0
3/2/2006	600 10 E	29	35.3	809	40.5	890	37.8	848	38.2	855	38.4	858	38.2

Table C-6. DCP test results from spring IOP1 at the Ford Farm RAS.

Station	Location	Date	Averge CBR within 6" bins						Average CBR within 12"			Source File
			0-6	6-12	12-18	18-24	24-30	30-36	0-12	12-24	24-36	
0m 10m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.92	7.02	3.97	3.01	2.62	3.12	6.00	3.49	2.81	DCPFordFarm0 10East.xls
0m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	5.06	4.87	1.77	2.04	3.44	4.21	4.98	1.93	3.60	DCPFordFarm0 10West.xls
0m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	6.86	5.74	4.42	2.94	3.03	2.46	6.37	3.60	2.80	DCPFordFarm0 CL.xls
120m 10m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	5.71	5.29	2.23	2.18	7.25	5.45	5.55	2.20	6.99	DCPFordFarm120 10East.xls
120m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.79	3.26	2.41	3.10	7.24	12.50	3.52	2.87	9.34	DCPFordFarm120 10West.xls
120m 2m East (estimated reading at 1002 mm)	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.06	1.91	2.43	3.70	3.10	3.42	2.57	2.91	3.18	DCPFordFarm120 2East.xls
120m 2m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.54	3.16	0.37	0.48	1.59	2.36	3.35	0.42	1.97	DCPFordFarm120 2West.xls
120m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.51	2.83	2.11	4.61	4.34	7.84	2.67	3.36	6.09	DCPFordFarm120 CL.xls
15m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.55	3.69	1.61	3.06	4.32	7.89	4.23	2.52	5.94	DCPFordFarm15 CL.xls
180m 10m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.57	6.15	3.01	2.48	3.39	3.21	5.36	2.74	3.30	DCPFordFarm180 10East.xls
180m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.19	8.91	4.87	3.89	6.13	3.51	6.99	4.26	5.01	DCPFordFarm180 10West.xls
180m 2m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.48	7.12	3.26	2.93	3.51	5.69	5.56	3.13	4.87	DCPFordFarm180 2East.xls
180m 2m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.70	6.90	6.59	3.88	5.70	6.98	5.68	5.43	6.41	DCPFordFarm180 2West.xls
180m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.46	5.24	2.53	3.48	3.25	4.75	4.13	3.01	4.11	DCPFordFarm180 CL.xls
240m 10m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.82	6.14	2.13	1.51	2.37	4.39	4.98	1.67	3.58	DCPFordFarm240 10East.xls
240m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.09	3.56	2.22	2.48	3.95	3.42	2.98	2.35	3.65	DCPFordFarm240 10West.xls
240m 2m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.05	5.50	2.87	2.10	1.93	2.90	4.52	2.61	2.58	DCPFordFarm240 2East.xls
240m 2m West (reading at 1004 mm is an estimate)	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.18	8.51	5.52	3.42	2.63	5.25	6.40	4.68	4.38	DCPFordFarm240 2West.xls
240m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.32	7.52	5.98	1.46	0.97	2.95	5.78	3.72	2.29	DCPFordFarm240 CL.xls
300m 10m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.85	6.29	4.36	4.35	2.31	2.93	5.25	4.35	2.68	DCPFordFarm300 10East.xls
300m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	6.28	4.84	2.84	2.83	3.91	5.70	5.56	2.83	4.93	DCPFordFarm300 10West.xls
300m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.31	3.63	6.74	7.96	9.37	8.72	3.10	7.35	9.08	DCPFordFarm300 CL.xls
360m 10m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.07	3.47	1.75	1.85	2.77	4.93	3.27	1.80	4.07	DCPFordFarm360 10East.xls
360m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.45	6.86	2.67	0.91	1.55	6.43	5.15	1.97	4.34	DCPFordFarm360 10West.xls
360m 2m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.23	3.07	2.68	2.18	4.19	7.30	2.65	2.43	6.13	DCPFordFarm360 2East.xls
360m 2m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.38	4.12	3.19	3.06	6.56	9.93	4.27	3.11	8.43	DCPFordFarm360 2West.xls
360m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.60	7.83	3.80	2.03	1.63	2.10	6.62	2.91	1.98	DCPFordFarm360 CL.xls
420m 10m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.17	4.54	1.94	2.23	4.81	3.96	3.36	2.08	4.44	DCPFordFarm420 10East.xls
420m 10m East (Duplicate test point)	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.80	4.99	2.79	2.50	4.27	4.06	4.05	2.67	4.17	DCPFordFarm420 10East2.xls
420m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.15	4.87	2.19	1.60	1.83	3.29	4.01	1.75	2.70	DCPFordFarm420 10West.xls
420m 2m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.42	3.92	4.40	2.90	4.33	6.71	3.42	3.65	5.81	DCPFordFarm420 2East.xls
420m 2m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.70	6.80	7.39	3.42	1.75	3.29	5.25	5.40	2.78	DCPFordFarm420 2West.xls
420m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	6.11	5.68	4.40	4.53	4.40	5.92	5.90	4.48	5.35	DCPFordFarm420 CL.xls
480m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.69	5.68	1.88	1.86	4.67	4.63	4.83	1.87	4.65	DCPFordFarm480 10West.xls
480m 2m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.55	6.08	2.31	0.97	1.23	2.02	5.32	1.77	1.76	DCPFordFarm480 2East.xls
480m 2m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.04	7.28	2.30	2.03	2.96	3.76	6.20	2.15	3.36	DCPFordFarm480 2West.xls
480m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	2.16	5.64	2.23	1.70	1.41	1.74	4.15	1.97	1.61	DCPFordFarm480 CL.xls
540m 10m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	1.35	4.97	1.75	1.82	2.77	3.26	3.53	1.79	3.02	DCPFordFarm540 10East.xls
540m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.84	4.17	2.12	2.86	4.39	3.50	4.05	2.44	4.03	DCPFordFarm540 10West.xls
540m 2m East, DCP began sinking under own weight at depth of 804 mm	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.27	9.31	3.08	1.83	2.11		7.15	2.37	2.11	DCPFordFarm540 2East.xls
540m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005, 1537 (local time)	3.34	6.68	5.61	6.24	7.10	3.89	5.20	5.92	6.03	DCPFordFarm540 CL.xls
585m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	5.05	5.37	1.76	2.85	2.85	4.47	5.23	2.30	3.66	DCPFordFarm585 CL.xls
60m 10m East	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.67	6.97	2.34	2.68	5.30	6.91	5.73	2.57	6.10	DCPFordFarm60 10East.xls
60m 10m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.66	2.93	1.45	3.10	4.95	6.14	3.34	2.39	5.35	DCPFordFarm60 10West.xls
60m 2m West	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.09	4.31	1.91	2.03	14.83	6.02	4.16	1.98	11.53	DCPFordFarm60 2West.xls
60m Centerline	Dean Ford Farm, Dupont, Indiana	4/20/2005	3.32	6.14	2.80	1.67	2.43	3.62	4.93	2.24	3.02	DCPFordFarm60 CL.xls
600m 10m East (Southwestern endpoint of runway)	Dean Ford Farm, Dupont, Indiana	4/20/2005	4.82	6.91	2.38	2.52	2.82	3.89	5.98	2.46	3.36	DCPFordFarm600 10East.xls
600m 10m West (Southwestern endpoint of runway)	Dean Ford Farm, Dupont, Indiana	4/20/2005, 1522 (local time)	4.00	6.55	2.30	3.16	4.70	5.78	5.13	2.59	5.30	DCPFordFarm600 10West.xls
600m Centerline (Southwestern endpoint of runway)	Dean Ford Farm, Dupont, Indiana	4/20/2005, 1517 (local time)	3.74	6.68	2.30	1.93	2.99	2.86	5.42	2.14	2.91	DCPFordFarm600 CL.xls

Table C-7. DCP test results from summer IOP2 at the Ford Farm RAS.

Station	Date	Average California Bearing Ratio (CBR) within 15 cm bins							Average California Bearing Ratio (CBR) within 30 cm bins			
		0-15	15-30	30-45	45-60	60-75	75-90	90-120	0-30	30-60	60-90	90-120
0m 10m East	8/4/2005	21.02	36.14	15.28	9.77	3.25			30.70	13.01	3.25	
0m 10m West	8/4/2005	11.86	11.42	8.72	9.18	6.97	5.28		11.61	8.96	6.82	
0m CenterLine	8/3/2005	22.18	21.97	13.89	8.52	5.82			22.06	11.81	5.82	
120m 10m East	8/4/2005	13.94	19.84	11.87	6.99	10.62			17.73	10.17	10.62	
120m 10m West	8/4/2005	22.54	20.55	11.13	8.22	7.25			21.42	9.78	7.25	
120m CenterLine	8/3/2005	25.74	30.76	10.86	4.00	4.73			28.70	8.81	4.73	
15m CenterLine	8/3/2005	14.08	16.96	7.70	8.69	7.46			15.74	8.19	7.46	
180m CenterLine	8/3/2005	11.63	11.55	5.68	5.67	6.11	6.47		11.59	5.68	6.15	
240m CenterLine	8/3/2005	11.88	21.41	14.12	7.66	5.73			18.39	11.53	5.73	
400m 10m East	8/4/2005	12.93	16.32	8.56	3.90	4.07			14.89	6.92	4.07	
300m 10m West	8/4/2005	18.80	26.89	16.82	14.46	10.91			23.63	15.73	10.91	
300m CenterLine	8/3/2005	9.12	10.42	3.99	3.51	2.54	2.43		9.82	3.79	2.52	
360m CenterLine	8/3/2005	15.73	20.20	8.24	11.83	7.18			18.47	10.34	7.18	
420m CenterLine	8/3/2005	14.98	22.04	13.68	8.62	7.32			19.58	11.41	7.32	
480m 10m East	8/4/2005	24.83	21.13	9.75	6.64	7.89			22.91	8.46	7.89	
480m 10m West	8/4/2005	18.62	21.23	13.62	7.50	5.87			20.11	11.30	5.87	
480m CenterLine	8/3/2005	11.43	15.92	9.93	6.17	4.46			14.38	8.46	4.46	
540m CenterLine	8/3/2005	12.64	22.18	11.24	3.94	4.28	5.63		19.22	9.05	4.44	
585m CenterLine	8/3/2005	34.70	37.78	16.96	7.28	7.08			36.51	13.94	7.08	
60m CenterLine	8/3/2005	13.77	23.23	12.44	4.86	7.03			20.00	10.13	7.03	
600m 10m East	8/4/2005	22.22	21.47	6.41	3.01	1.44			21.84	5.28	1.44	
600m 10m West	8/4/2005	16.59	23.28	11.03	8.85	5.50			20.77	10.18	5.50	
600m CenterLine	8/3/2005	24.74	30.69	14.02	6.37	6.39			28.60	11.56	6.39	

Table C-8. DCP test results from fall IOP3 at the Ford Farm RAS.

Station	Location	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
			0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
0 m 10 m East	Dean Ford Farm, Dupont, IN	11/1/2005	7.61	12.91	8.25	5.09	2.95	3.17		10.26	6.89	3.06	
0 m 10 m West	Dean Ford Farm, Dupont, IN	11/1/2005	3.27	9.17	4.99	5.78	3.92	8.83		7.20	5.43	6.38	
0 m Centerline; testing on a tire track	Dean Ford Farm, Dupont, IN	10/30/2005	3.37	7.00	3.86	2.35	0.85	1.76		5.39	3.11	1.58	
120 m 10 m East	Dean Ford Farm, Dupont, IN	11/1/2005	3.53	7.70	3.41	2.63	5.71	5.38		6.31	2.98	5.60	
120 m 10 m West (repeat)	Dean Ford Farm, Dupont, IN	11/1/2005	6.77	11.46	7.11	5.16	3.37	7.75		9.12	6.33	6.16	
120 m 10 m West; may have hit a rock	Dean Ford Farm, Dupont, IN	11/1/2005	6.61	13.65	10.42	9.98	8.59	6.22		11.09	10.20	7.57	
120 m Center-line	Dean Ford Farm, Dupont, IN	10/30/2005	5.05	5.82	2.78	5.68	8.67	5.09		5.47	4.63	7.48	
15 m Centerline	Dean Ford Farm, Dupont, IN	10/30/2005	3.84	7.39	3.31	5.90	5.16	3.45		5.97	4.60	4.21	
120 m Center-line	Dean Ford Farm, Dupont, IN	10/30/2005	5.51	8.68	3.63	3.11	3.82	4.30		7.24	3.39	4.03	
120 m Center-line	Dean Ford Farm, Dupont, IN	10/30/2005	5.55	9.03	7.32	9.61	5.25	6.92		7.58	8.37	5.66	
300 m 10 m East	Dean Ford Farm, Dupont, IN	11/1/2005	5.52	9.04	4.12	2.70	2.74	2.70		7.44	3.51	2.72	
300 m 10 m West	Dean Ford Farm, Dupont, IN	11/1/2005	7.27	12.81	8.95	5.34	5.47	4.41		10.25	7.35	4.94	
300 m Center-line	Dean Ford Farm, Dupont, IN	10/30/2005	4.91	6.81	6.19	5.44	9.93	17.24		5.86	5.85	13.30	
360 m 10 m East	Dean Ford Farm, Dupont, IN	10/31/2005	5.39	7.00	3.10	4.19	4.60	6.45		6.28	3.70	5.53	
360 m 10 m West	Dean Ford Farm, Dupont, IN	10/31/2005	5.52	10.22	5.58	3.53	6.09	8.51		8.09	4.81	7.43	
360 m Center-line	Dean Ford Farm, Dupont, IN	10/30/2005	2.50	4.18	3.11	3.06	5.91	5.72		3.62	3.08	5.86	

Table C-8 (cont'd). DCP test results from fall IOP3 at the Ford Farm RAS (Cont'd).

420 m 10 m East	Dean Ford Farm, Dupont, IN	10/31/2005	5.42	3.80	5.59	8.38	5.45	4.08		4.70	6.88	4.86	
420 m 10 m West	Dean Ford Farm, Dupont, IN	10/31/2005	7.26	7.80	5.61	6.40	6.91	6.17		7.48	6.05	6.58	
420 m Center-line	Dean Ford Farm, Dupont, IN	10/30/2005	5.07	9.21	7.44	5.83	10.46	7.97		7.55	6.64	9.72	
480 m 10 m East	Dean Ford Farm, Dupont, IN	10/31/2005	6.31	11.10	9.95	5.41	7.91	7.53		9.26	7.68	7.76	
480 m 10 m West	Dean Ford Farm, Dupont, IN	10/31/2005	7.19	8.62	4.68	6.02	9.28	6.84		7.96	5.54	8.54	
480 m Center-line	Dean Ford Farm, Dupont, IN	10/30/2005	7.94	10.19	7.45	5.88	3.04	3.77		8.84	6.93	3.31	
540 m Center-line; DCP broke	Dean Ford Farm, Dupont, IN	10/30/2005	4.54	6.05	3.86	1.31	5.95			5.54	3.01	5.95	
585 m Center-line	Dean Ford Farm, Dupont, IN	10/31/2005	6.40	8.30	6.03	6.20	6.71	4.61		7.44	6.11	5.93	
60 m Centerline	Dean Ford Farm, Dupont, IN	10/30/2005	6.05	9.00	3.84	3.96	4.85	6.77		7.53	3.90	5.71	
600 m 10 m East	Dean Ford Farm, Dupont, IN	10/31/2005	4.83	7.19	4.58	3.39	5.02	3.27	3.65	6.14	3.83	4.15	3.65
600 m 10 m West	Dean Ford Farm, Dupont, IN	10/31/2005	6.53	3.95	2.42	3.11	3.69	4.72		5.59	2.76	4.14	
600 m Center-line	Dean Ford Farm, Dupont, IN	10/31/2005	5.76	4.92	3.14	2.91	3.38	4.76		5.42	3.03	3.72	

Table C-9. DCP test results from winter IOP4 at the Ford Farm RAS.

Station	Date	Average CBR within 15-cm bins							Average CBR within 30-cm bins			
		0–15	15–30	30–45	45–60	60–75	75–90	90–120	0–30	30–60	60–90	90–120
0 M 10 M East	3/2/2006	5.52	6.63	3.89	2.74	4.70	4.39		6.21	3.43	4.60	
0 M 10 M West	3/2/2006	4.11	3.99	1.86	3.71	7.35	12.83		4.05	3.16	9.82	
0 M Centerline	3/2/2006	5.52	6.72	7.54	4.55	6.38	5.45		6.23	6.13	6.05	
120 M Centerline	3/2/2006	6.47	4.14	2.11	1.45	0.69			5.20	1.98	0.69	
15 M Centerline	3/2/2006	5.55	7.09	2.41	2.79	5.05	9.00		6.42	2.62	6.90	
180 M Centerline (repeat)	3/2/2006	4.27	6.65	1.76	1.44	4.89	4.41		5.80	1.60	4.67	
180 M Centerline	3/2/2006	5.89	6.83	3.35	1.08	0.21	2.85		6.44	2.90	1.97	
240 M Centerline	3/2/2006	3.88	6.49	8.65	8.69	5.95	3.08		5.74	8.67	5.23	
300 M 10 M East	3/2/2006	4.70	6.61	1.86	2.14	3.58	5.27		5.93	2.02	4.26	
300 M 10 M West	3/2/2006	4.67	8.18	4.65	5.41	4.50	6.08		7.01	5.06	5.23	
300 M Centerline	3/2/2006	6.61	7.52	5.92	7.91	8.50	9.37		7.15	7.06	8.80	
360 M Centerline	3/2/2006	4.69	5.84	2.17	3.58	10.08	9.14		5.40	3.11	9.77	
420 M Centerline	3/2/2006	4.39	8.14	3.05	2.64	2.86	2.56		6.97	2.87	2.77	
480 M Centerline	3/2/2006	7.05	8.44	5.76	5.90	4.08	3.56		7.89	5.82	3.90	
540 M Centerline	3/2/2006	2.14	4.71	3.56	0.92	2.26	2.95		3.94	2.68	2.64	
585 M Centerline	3/2/2006	1.42	5.75	2.63	2.52	4.83	7.85		4.88	2.57	6.34	
60 M Centerline	3/2/2006	4.83	6.16	2.45	3.89	4.84	5.91		5.63	3.31	5.34	
600 M 10 M East	3/2/2006	5.93	8.32	4.72	0.54	2.20	6.89		7.61	4.02	5.01	
600 M 10 M West	3/2/2006	5.22	4.93	2.26	1.57	1.68	2.61		5.07	1.96	2.15	
600 M Centerline	3/2/2006	2.53	5.28	3.84	1.62	2.61	9.36		4.53	3.10	7.43	

Appendix D: Calibration of Soil Moisture Measuring Instruments[1]

Introduction

Soil moisture is a key OLS system parameter because of its significance for estimating soil strength. Soil strength measurements were made at the OLS field sites using a dynamic cone penetrometer. Soil moisture measurements typically were made near soil strength measurements, allowing moisture to be used in relationships used to predict soil strength. Although other soil parameters, e.g., texture and density, are important factors in predicting soil strength, soil moisture is the only soil physical variable that has an important impact on soil strength and also can vary over a large range in a short time. Therefore, because soil strength is as important to the success of an OLS as is its flatness, smoothness, and freedom from obstructions, the accuracy of soil moisture measurements has a significant effect upon the prediction of soil strength. In the case of the OLS field measurements at El Centro NAF, Fort Bliss, and in southern Indiana, soil strength prediction methods are validated using the in situ soil moisture and soil strength measurements.

Measurement of soil moisture during the OLS field validation program required the use of several soil moisture measurement techniques. Electronic instruments were used for most measurements because they provided rapid response, and because they were able to provide soil moisture time series at a few locations. Measurements also were made with a Troxler nuclear gauge because moisture measurements were easily obtained as density measurements were made with this instrument. Finally, soil moisture measurements were made by taking samples either with a drive cylinder, or by taking soil samples with a spoon. These samples were then weighed, oven-dried, and reweighed to determine the percent soil moisture in the samples as a function of weight.

In some cases, soil moisture measurements were made with multiple technologies at the same sampling locations to assess how well the different measurement methods agreed. In these cases there often was disagree-

[1] Appendix D was written by Charles C. Ryerson, Kevin L. Bjella, Lynette A. Barna, Christopher M. Berini, Forrest R. Scott, Keran J. Claffey, and Gary E. Phetteplace.

ment among the instruments. Also, in some cases instruments would provide values that were not consistent with physical possibility.

The purpose of this appendix is to assess which instruments provided the most accurate soil moisture measurements and to assess how well other instrument measurements compared to the most accurate measurements. It concludes with recommendations of how to use measurements from each of the measurement methods.

OLS soil moisture measurement methods

Electronic instruments, as indicated above, were used to make most OLS soil moisture measurements. Electronic instruments are fast and allow time series to be made when monitored with a data logger. Dynamax instruments were used at the OLS field sites. The Dynamax ML2 was used for all sample location measurements at the soil surface. It also was used to measure soil moisture at depth, either by measuring moisture in the bottom or sides of a soil pit, or by measuring moisture in increments as a hole is augured (Fig. D-1). The ML2 technology is described in the instrument literature (Delta-T Devices 1999). Measurements are made by pushing 60-mm-long tines on the base of the instrument into the soil; the value displayed on the attached HH2 digital readout represents the soil moisture measured within the soil volume encompassed by the tines.

Figure D-1. Using ML2 and HH2 readout to measure soil moisture at depth within auger hole.

Soil moisture time series measurements were made with the Dynamax PR1 and PR2 instruments. The PR1 was used at the North Vernon, Indiana, airport weather station site, and the PR2 was used at the Ford Farm, Fort Bliss, and El Centro NAF OLS weather station sites. The PR1 and PR2 use a technology somewhat different from the ML2; they consist of a 1-m rod that is placed inside a sleeve in the soil, with soil moisture measured at fixed depths when interrogated by a data logger (Delta-T Devices 2001, 2004) (Fig. D-2). Typically, the instruments were located approximately 1 km from the OLSs, at the OLS weather stations. However, some sleeves were placed in the El Centro NAF and Fort Bliss Runway Analysis Sites (RAS), and spot measurements of soil moisture content with depth were made at those locations.

Figure D-2. Dynamax PR1 ThetaProbe inside (left) and outside (right) of access tube (Delta-T Devices 2001). The PR2 is identical in appearance.

The PRI and PR2 instruments are of similar construction, but their electrical response to soil moisture is considerably different, as indicated in the instrument literature (Delta-T Devices 2001, 2004). Responses by the PR1 instrument with moisture contents that were inconsistent with possible soil moisture magnitudes, such as providing moisture volume fractions greater than one, provided the impetus to conduct the work described in this appendix (Fig. D-3).

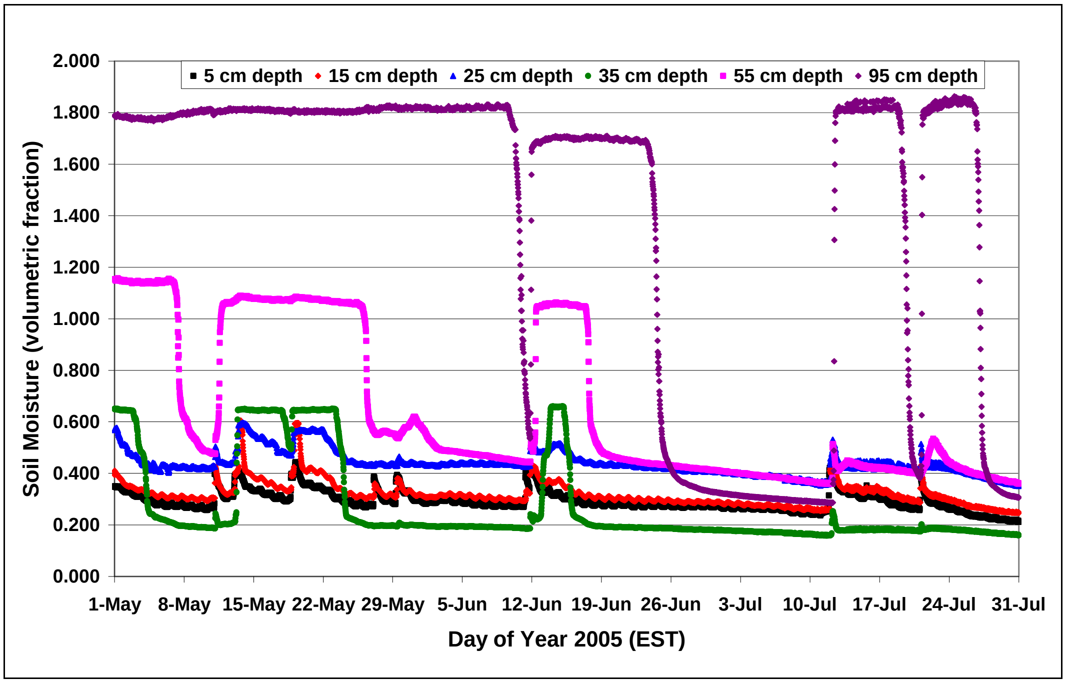


Figure D-3. Soil moisture measured by PR1 probe at North Vernon Airport. Note larger than physically possible volume fractions at depths of 55 cm and 95 cm.

Soil moisture measurements also were made with the Troxler 3440 nuclear gauge. The Troxler was used primarily to make soil density measurements at the RASs. However, because the instrument also measures soil moisture to provide moisture-corrected soil density values, moisture content also was recorded (Fig. D-4). The Troxler 3440 uses an americium:beryllium radiation source to emit neutrons from the base of the instrument. The neutrons collide with water hydrogen atoms and slow. The instrument reads the number of backscattered neutrons that have been slowed by collisions with hydrogen. Generally, the instrument measures moisture content in the soil volume down to a depth of about 10 cm immediately below the instrument base. Depth of readings penetrates deeper as soil becomes drier, extending to a depth of about 15 cm (Troxler 2006).

Soil moisture also was measured by oven-drying samples that had been removed from the field. Spoon and drive cylinder samples were obtained from soil pits, the soil surface, and from cuttings as auger holes were drilled.

Measurement accuracy

The electronic instrument measurements initially were suspect because the PR1 instrument provided soil moisture contents larger than physically

possible—greater than saturation at depths where saturation may have occurred (Fig. D-3). Also, visual comparisons of ML2 and PR2 measurements with one another, and with oven-dry and Troxler measurements, showed considerable scatter (Fig. D-5).

Figure D-4. Troxler nuclear gauge (yellow instrument) in moisture-reading configuration at the base of the soil pit. The Dynamax ML2 is held ready for measurement of soil moisture content, with the four stainless steel measuring rods visible at the right pit wall.

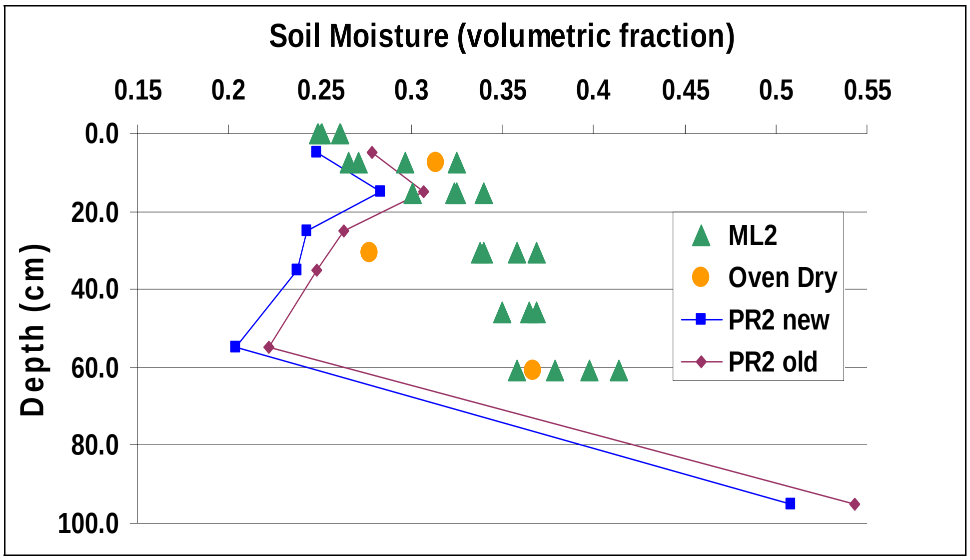


Figure D-5. Scatter of moisture readings at Ford Farm with different technologies. Note that the PR2 observations were made approximately 1 km from the other observations.

The Dynamax instruments all operate by assuming that soil moisture content is approximately proportional to the dielectric properties of the soil (Delta-T Devices 1999, 2001, 2004). The soil moisture is then computed from a polynomial fit between the instrument voltage and the soil moisture for a generic mineral soil. In examples provided by Dynamax, when considering errors caused by "soil heterogeneity, the number of samples taken, the extent to which it is possible to perform an accurate calibration on an 'undisturbed' sample, and inserting the probe without causing air pockets or localized soil compression," possible errors in measurements can be ±5% for a probe calibrated for a given soil, and ±6% for measurements where the probe is not calibrated to the specific soil (Delta-T Devices 1999, 2001, 2004).

The Troxler nuclear gauge measures soil moisture, as described above, by measuring the receipt of neutrons that are slowed by hydrogen atoms within soil water. Because neutrons are emitted and reabsorbed at the base of the instrument when it is placed upon the soil surface, an important source of moisture measurement error for the nuclear gauge is air gaps between the base of the instrument and the soil (Rollings 2006; Rollings and Rollings 1996). In general, Troxler instrument measurements should compare within 2% of oven-dry values (Myers 2006).

The most acceptable method of measuring soil moisture is the oven-dry gravimetric method (Rollings 2006). Though error may be caused by poorly calibrated balances, loss of soil between weighings, and other procedural problems, it is considered the "standard" method of measuring soil moisture. Gravimetric water content may be converted to volumetric water content by multiplying gravimetric moisture content by the dry density of the soil and dividing by the unit weight of water. A major source of error can be the soil dry density measurement, which is most accurate when measured by a Troxler nuclear instrument (Rollings and Rollings 1995; Rollings 2006).

As a result of these sources of instrument error, and because most of the OLS RAS measurements were made with the Dynamax instruments because of their ease of use, a recalibration of the Dynamax instruments was conducted. The recalibration was conducted after obvious instrument malfunctions, such as readout device errors, had been corrected.

Dynamax instrument calibrations

Instrument operation

Soil moisture was measured electronically with three models of Dynamax instruments: the ML2, PR1, and PR2, manufactured by Delta-T Devices Ltd., UK. Measurement is accomplished by inducing a 100-MHz sinusoidal signal into the soil with either a pair of stainless steel bands (PR1 and PR2) (Fig. D-2), or four stainless steel rods (ML2) (Fig. D-4). The impedance of these conductors varies with the impedance of the soil, which consists of two components: the bulk dielectric constant and the ionic conductivity. The 100-MHz signal minimizes the effects of the ionic conductivity. Thus, the moisture measurements rely almost exclusively on the bulk dielectric constant. The dielectric constant of water (~81) is much higher than that of soil (3 to 5) and air (1). Because the dielectric constant of water is significantly larger than that of soil mineral and organic materials or air, the overall dielectric constant of the soil is primarily determined by its water content.

The impedance of the conductor affects the reflection of the 100-MHz signal, and the reflections combine with the applied signal to form a voltage standing wave along the conductor. The output of the instrument is an analog voltage proportional to the difference in amplitude of this standing wave at two points, and this forms a sensitive measure of the soil water content. The correlation between the square root of the dielectric constant ($\sqrt{\varepsilon}$) and the volumetric moisture content (θ) is nearly linear for many soil types, and is reported as $m^3\ m^{-3}$. In the field, either the measured voltage or θ can be collected using the manufacturer's handheld data collector, or a commercial data logger can be installed.

The ML2 consists of four 60-mm stainless rods attached parallel to each other and mounted in a plastic base. The rods are inserted into the soil and a measurement is taken with the handheld HH2 data readout displaying soil moisture either in voltage or θ. The ML2 also can be buried for prolonged measurements at depth, but this was not done in the OLS program.

The PR1 and PR2 are 1-m-long multidepth probes with sensors arranged at 100, 200, 300, 400, 600, and 1000 mm from the top of the rod. A thin fiberglass sleeve is installed into the ground by first auguring a hole into the soil, installing, and backfilling, ensuring that no air voids occur along the length of the sleeve (Fig. D-6). The probe is either permanently placed

inside the sleeve and connected to a data logger, or can be inserted and removed at each site visit. The advantage of the PR1 and PR2 is the ability to take in situ measurements at determined depths fairly easily.

Figure D-6. Top of PR1 at North Vernon Airport protruding above soil surface when in monitoring position. White plastic sleeve is visible below dark instrument top.

Instrument calibration

Polynomial equations are provided by the manufacturer, allowing the user to input voltage and determine $\sqrt{\varepsilon}$. The equations are best-fit curves to the square root of the dielectric constant versus measured voltages, and they are significantly different among the three instruments. The equations are listed as follows:

ML2

$$\sqrt{\varepsilon} = 1.07 + 6.4V - 6.4V^2 + 4.7\,V^3; \qquad (1)$$

PR1

$$\sqrt{\varepsilon} = 0.88 + 4.24V + 65.6V^2 - 272.7\,V^3 + 402.9V^9; \qquad (2)$$

PR2

$$\sqrt{\varepsilon} = 1.125 - 5.53V + 67.17 V^2 - 234.42V^3 + 413.56 V^4 - 356.68 V^5 + 121.53 V^6. \quad (3)$$

Applying these equations with voltages from known soil moistures allows the determination of two calibration constants, a_0 and a_1, derived from linear regression, where a_0 is the y-intercept and a_1 is the slope of the line. These can then be applied to give θ where

$$\sqrt{\varepsilon} = a_1 \cdot \theta + a_0. \quad (4)$$

For soil moisture determination, Equations 1–3 are rewritten as

ML2

$$\theta = [(1.07 + 6.4V - 6.4V^2 + 4.7 V^3)-a_0]/a_1; \quad (5)$$

PR1

$$\theta = [(0.88 + 4.24V + 65.6V^2 - 272.7 V^3 + 402.9V^9)- a_0]/a_1; \quad (6)$$

PR2:

$$\theta = [(1.125 - 5.53V + 67.17 V^2 - 234.42V^3 + 413.56 V^4 - 356.68 V^5 + 121.53 V^6) - a_0] / a_1. \quad (7)$$

The HH2 handheld readout applies Equations 5–7 to display θ if desired. The calibration constants can be specified by the user, and the manufacturer suggests using the values listed in Table D-1 for general cases where a soil-specific calibration has not been performed and the soils are not high in clay content, very stony, desiccate on drying, or are extremely saline.

Table D-1. Manufacturer calibration constants.

Soil type	a_0	a_1
Mineral	1.6	8.4
Organic	1.3	7.7

Dynamax instrument comparisons

As described above, for all three instruments the manufacturer states that the effective measurement error is ±0.06 $m^3 m^{-3}$ considering all factors that can affect measurement quality without calibration, and ±0.05 $m^3 m^{-3}$ with soil specific calibration. To verify this, a column of soil (USCS SM-ML soil) was assembled in a 20-cm-diameter, meter-long plastic cylinder, which was placed upright and loaded with the soil and a PR1/PR2 sleeve installed in the middle (Fig. D-7). Six 4.5-cm-diameter holes were drilled on the outside of the cylinder at the same depth as the sensor rings for the PR1/PR2 probes to allow for coincident measurement using the ML2. To allow verification at a variety of moisture contents, known volumes of water were added to the column to wet the soil to specific moisture contents, and measurements then were made after time had elapsed to allow moisture in the column to equilibrate. However, it was recognized that soil moisture most probably was not completely uniform from top to bottom of the column due to permeability and capillary action.

Figure D-7. Soil column for testing PR1, PR2, and ML2 probes. The PR1 and PR2 sleeve ran through the center of the column. The black, sealed holes on the side were used to measure moisture with the ML2 at the same depths as the PR1 and PR2 sensor rings.

Using the manufacturer's calibration constants for mineral soil, and estimating the column moisture content at 15%, average values for each instrument were calculated and are listed in Table D-2, columns two and three. The ML2 performed most accurately with a difference of 2.0% from the estimated soil volumetric moisture content. The PR1 performed the poorest, with a 94% difference. These results suggested that a soil-specific calibration for each instrument was necessary, using the four soils from the OLS field work: North Vernon Airport, the Ford Farm, El Centro NAS, and Fort Bliss. A calibration also was conducted on the soil in the column to verify the results.

Table D-2. Comparison of default and calibrated constants for θ of 15% in the column soil.

	θ using manufacturers' constants	Error from estimated moisture content of 15%	θ using calibrated constants	Error from estimated moisture content of 15%
PR1	29.1 %	+ 94 %	17.1 %	+14 %
PR2	19.5 %	+ 30 %	14.2 %	–5.3 %
ML2	14.7 %	–2.0 %	12.2 %	–18.6 %

Dynamax soil-specific calibrations

An apparatus was devised that allowed for pre-wetted soil to be placed around a PR1/PR2 sleeve, and the PR1 and PR2 then were tested by lowering each sensor to the midpoint of the soil section and taking three readings by rotating the probe 120° between each reading (Fig. D-8). Oven-dry measurements of the soil moisture content were not made, thereby limiting the accuracy of the calibrations. Each soil section averaged approximately 23 cm in diameter and 10 cm in thickness. The ML2 was tested by taking five readings at different locations on the surface of the soil section. The four project soils were tested at moisture contents of 0.0%, 10.0%, and near saturation, which varied for each soil from 15.0% to 25.0%. The column soil was tested at 0.0% and 20.0% only. All soil moisture contents were established by adding a known volume of water to the soil samples.

Results were averaged for each depth for the PR1 and PR2 probes, and for the five readings taken with the ML2, and the data plotted to obtain the soil-specific calibration constants (Table D-3). Differences between the calibrated and default constants were found for all soils; however, exceptionally large changes occurred in the a_1 constant in the Fort Bliss and El Centro soils.

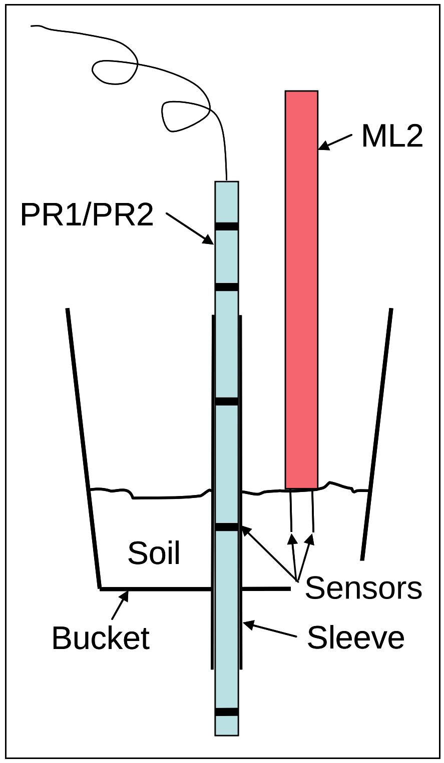


Figure D-8. Cross section of apparatus to measure soil moisture in OLS field soils with the ML2, PR1, and PR2 probes.

Table D-3. Calibration constants for each instrument at each depth, in millimeters.

		Ford Farm		Airport		Ft. Bliss		El Centro		Column Soil		Default	
PR-1	**Depth**	**a0**	**a1**	**a0**	**a1**	**a0**	**a1**	**a0**	**a1**	**a0**	**a1**	**a0**	**a1**
	100	1.63	10.8	1.62	13.95	1.75	9.8	1.78	9.51	2.00	10.3		
	200	1.61	11.5	1.68	14.88	1.77	12.0	1.83	9.51	1.97	11.3		
	300	1.53	11.5	1.62	15.07	1.73	13.0	1.76	10.2	1.89	11.4		
	400	1.51	11.6	1.57	15.17	1.73	12.3	1.71	9.78	1.87	11.5		
	600	1.89	10.3	1.95	17.59	1.96	8.29	2.07	9.94	2.19	12.6		
	100	2.22	7.65	2.06	12.65	1.95	11.3	2.10	11.4	2.45	12.2		
	Average	**1.57**	**11.3**	**1.62**	**14.8**	**1.74**	**11.8**	**1.77**	**9.76**	**1.93**	**11.1**	**1.60**	**8.40**
PR-2	100	1.43	8.13	1.39	8.79	1.70	5.39	1.66	4.83	1.77	10.0		
	200	1.47	8.20	1.46	8.59	1.70	5.54	1.66	4.82	1.84	10.1		
	300	1.48	8.26	1.46	9.19	1.71	5.69	1.67	4.90	1.83	10.2		
	400	1.42	8.80	1.48	9.07	1.73	6.18	1.68	5.05	1.82	10.0		
	600	1.47	8.32	1.46	9.81	1.73	5.73	1.59	5.47	1.86	10.1		
	1000	1.49	8.07	1.38	7.29	1.61	6.02	1.46	6.04	1.72	9.75		
	Average	**1.46**	**8.30**	**1.44**	**8.79**	**1.70**	**5.76**	**1.62**	**5.19**	**1.81**	**10.0**	**1.60**	**8.40**
ML-2	**Average**	**1.46**	**11.4**	**1.50**	**10.5**	**1.62**	**10.2**	**1.57**	**9.99**	**1.71**	**9.33**	**1.60**	**8.40**

* For PR-1 Data in red are omitted from the average due to possible faulty sensors.

Applying the new constants to the 15% column soil moisture content using Equations 5–7 allowed comparison of the default constants to the new constants. These results, listed in columns four and five of Table D-2, still produce errors larger than ±0.05%. The error for the PR1 and PR2 probes with the new constants is smaller than the error with the default constants; however, the ML2 error increased.

Statistical comparisons

Comparisons were made between coincident oven-dried soil moisture measurements and the ML2 to determine whether they were statistically from the same population. If the electronic and oven-dry measurements were found to be statistically from the same population, then it may be argued that the electronic measurements may be used with some confidence.

Only ML2 and oven-dry measurement pairs were compared. Troxler nuclear gauge moisture measurements are considered generally less accurate than oven-dried moisture contents, so comparisons were not made between the Troxler and other moisture measurements. PR1 and PR2 measurements also were not compared to oven-dry moisture contents because paired observations—those made at essentially the same location and time—were not available.

Statistical comparisons were made in the following groupings: North Vernon Airport, Ford Farm, Fort Bliss, and El Centro NAS. North Vernon Airport and Ford Farm also were combined into an eastern sites group, and El Centro NAS and Fort Bliss were combined into a western sites group.

Nonparametric statistical methods were used for comparison because measurements often were not normally distributed, and sample sizes often were sufficiently small that assumptions were not satisfied for parametric statistics, making nonparametric statistics necessary. The Wilcoxon difference of means test was used to determine whether oven-dried and ML2 default calibration moisture magnitudes, and the oven-dried and ML2 soil-specific calibration moisture magnitudes, were from the same population. The Spearman rank correlation coefficient was used to determine whether there was a significant correlation between the pairs of measurements. In all cases, the probabilities were set at $\rho > 0.05$, not significant; $\rho = 0.01$ to 0.05, significant; $\rho = 0.001$ to 0.01, very significant; and $\rho < 0.001$, extremely significant. Software used for nonparametric analyses was GraphPad (1995), and for plots and linear regressions was Microsoft Excel.

North Vernon Airport, Ford Farm, and eastern sites

Correlations between oven-dry and ML2 soil moisture percentages were very low (column 4), and not significant (column 5) with the small sample

sizes available in Indiana, 27 at the North Vernon Airport, and 22 at Ford Farm (column 10) (Table D-4). All r^2 were less than 0.06. Figures D-9–D-11 show the large scatter in the oven-dry to ML2 relationships.

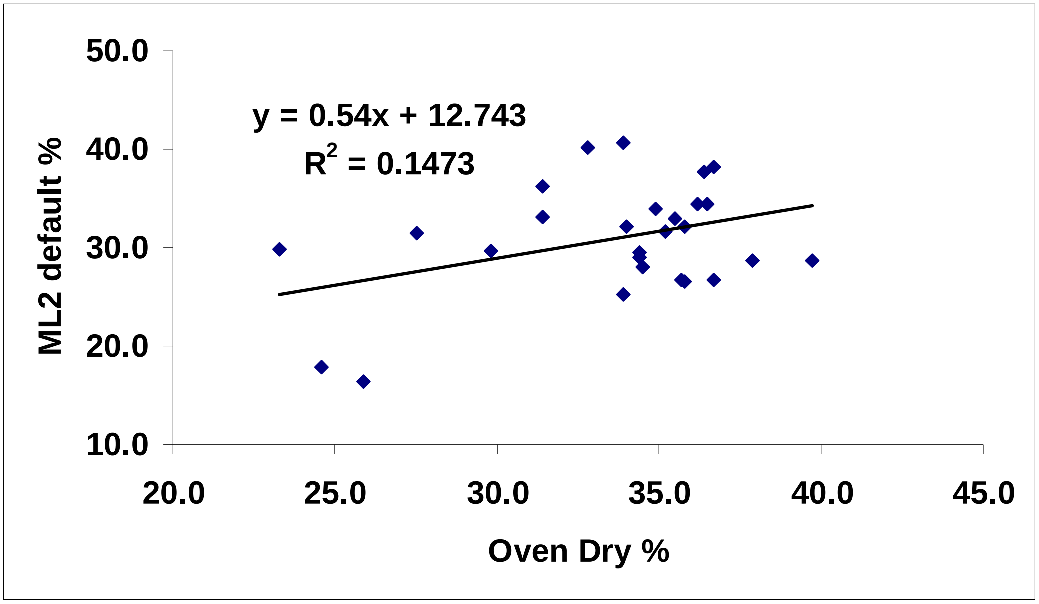
Only one of the Wilcoxon difference of means tests, for the Ford Farm default ML2 calibration, showed no significant difference between the oven-dry and electronic soil moisture measurements (columns 2 and 3) (Table D-4). At North Vernon Airport and Ford Farm individually, and at the two sites combined, the two-tailed ρ values and the differences between the oven-dry and electronic measurements means show that the default calibration provided by Dynamax compared better to the oven-dry samples than did the soil-specific calibrations. The mean differences (column 9) also were smallest for these cases (Table D-4).

Table D-4. Comparisons between oven-dry and ML2 soil moisture percentages in southern Indiana.

1	2	3	4	5	6	7	8	9	10
	Wilcoxon two-tailed ρ	Sig*	Spearman *r*	One-tailed ρ	Sig*	Oven-dry mean**	ML2 mean**	Mean difference**	N
Airport default	0.0200	S	0.10	0.3057	NS	33.5	30.8	2.7	27
Airport calibrated	<0.0001	S	0.06	0.3825	NS	33.5	24.5	9.0	27
Ford default	0.0634	NS	−0.24	—	—	33.8	30.3	3.5	22
Ford calibrated	<0.0001	S	−0.25	—	—	33.8	22.9	10.9	22
Eastern default	0.0034	S	−0.05	—	—	33.6	30.6	3.0	49
Eastern calibrated	<0.0001	S	−0.01	—	—	33.6	23.8	9.8	49

* Sig is significance of the relationship. S is significant at a probability of 0.05, and NS is not significant at a probability of 0.05.

** Volumetric soil moisture content in percent.



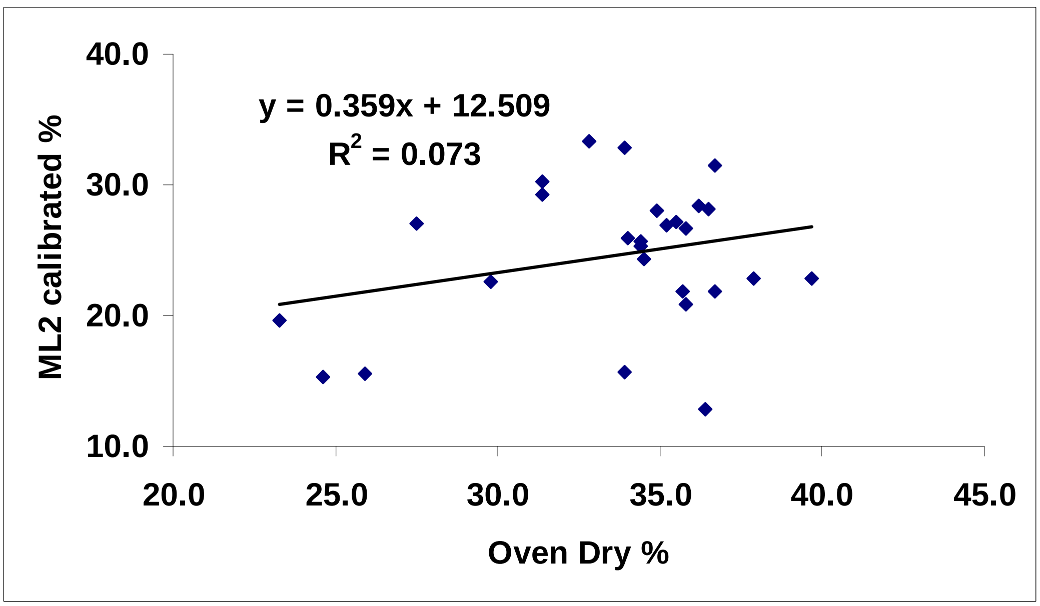
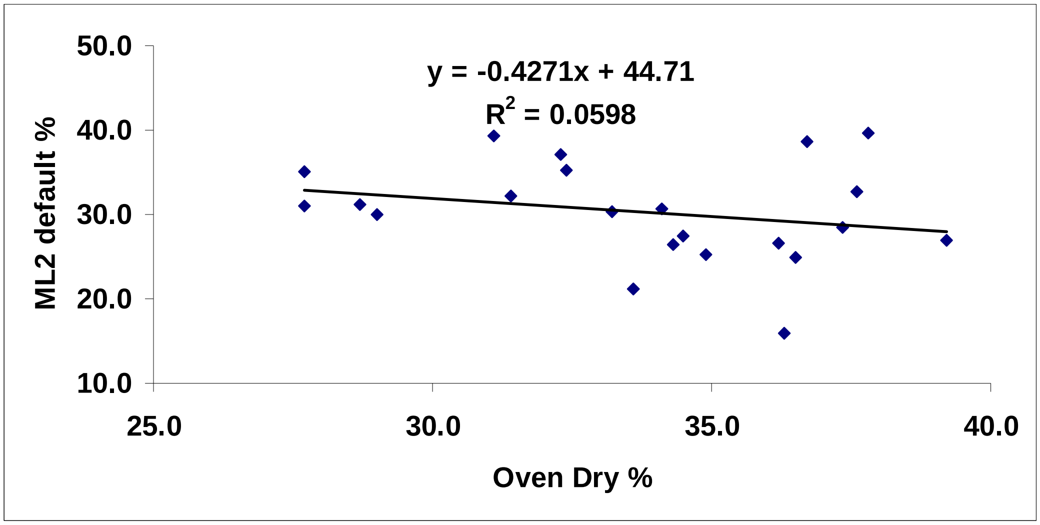


Figure D-9. Scatter plots and Pearson parametric linear regressions for North Vernon Airport moisture contents. Oven-dry versus ML2 default calibration (top) and soil-specific calibration (bottom).



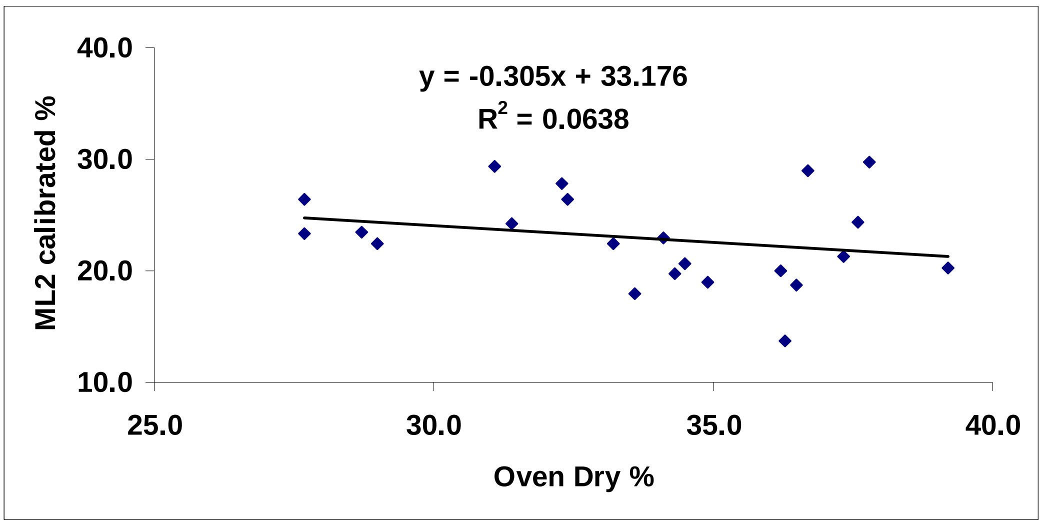


Figure D-10. Scatter plots and Pearson parametric linear regressions for Ford Farm moisture contents. Oven dry versus ML2 default calibration (top) and soil-specific calibration (bottom).

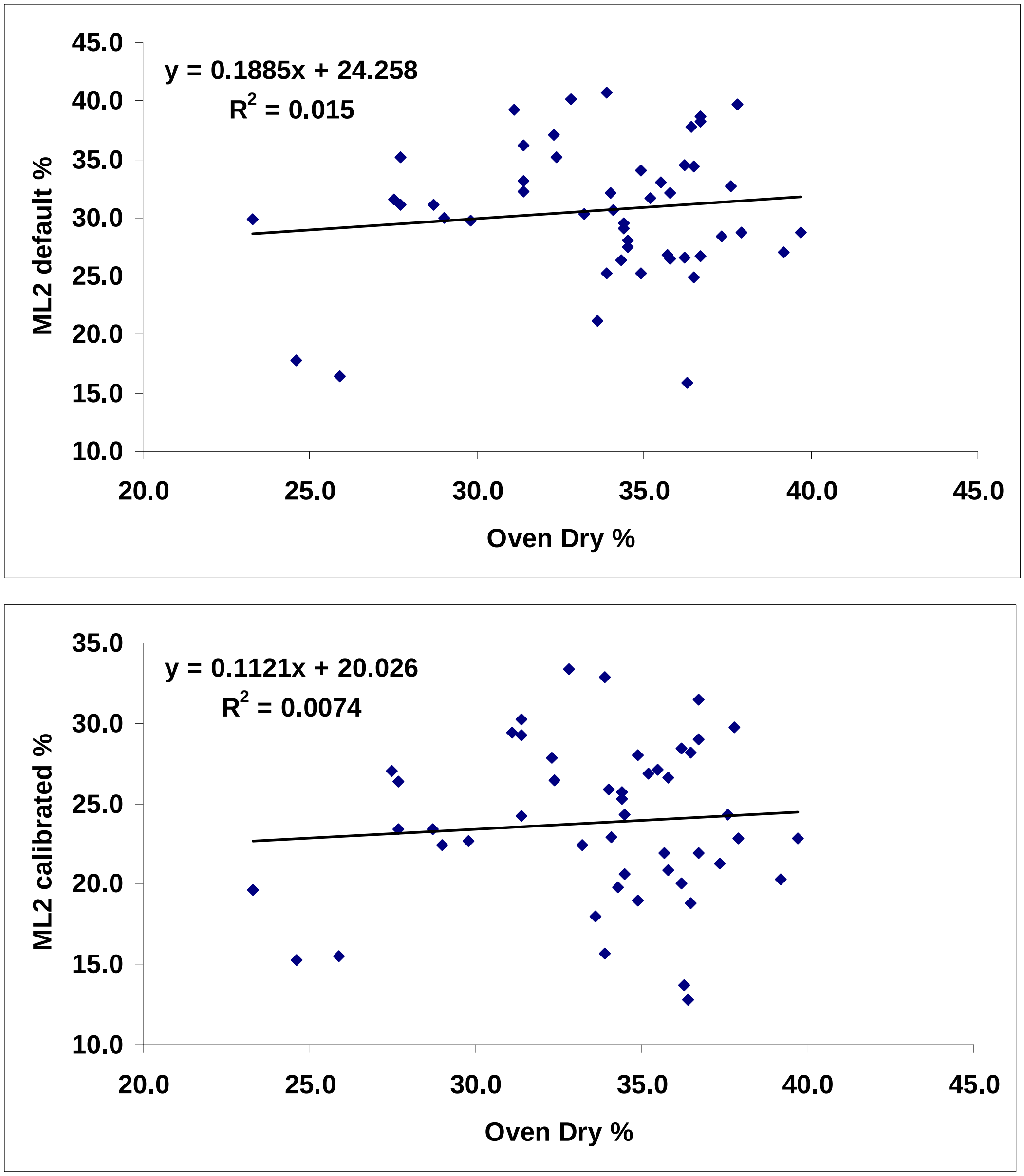


Figure D-11. Scatter plots and Pearson parametric linear regressions for the eastern site moisture contents. Oven-dry versus ML2 default calibration (top) and soil-specific calibration (bottom).

Fort Bliss, El Centro NAS, and western sites

Correlations between oven-dry moisture contents and the ML2 electronic measurements were higher in the western soils than in the eastern soils, with r^2 values all larger than 0.41 (Table D-5). Although scatter plots of the Fort Bliss, El Centro NAS, and combined sites all show considerable scatter, the correlations are all significant (Figs. D-12–D-14; Table D-5).

The Wilcoxon difference of means test, however, showed large differences between the oven-dry and ML2 default and calibrated soil moisture contents at Fort Bliss and at El Centro NAS (columns 2 and 3) (Table D-5). However, relationships were not significant, meaning that there is no significant difference between the means when the moisture measurements from both western sites were compared (Western default and Western calibrated rows, columns 2 and 3) (Table D-5). Therefore, statistical assessment of whether the default ML2 algorithms or the algorithms calibrated with the field soils compare better with the oven-dry soils is difficult to determine from the statistical analyses alone.

Table D-5. Comparisons between oven-dry and ML2 soil moisture percentages in western sites.

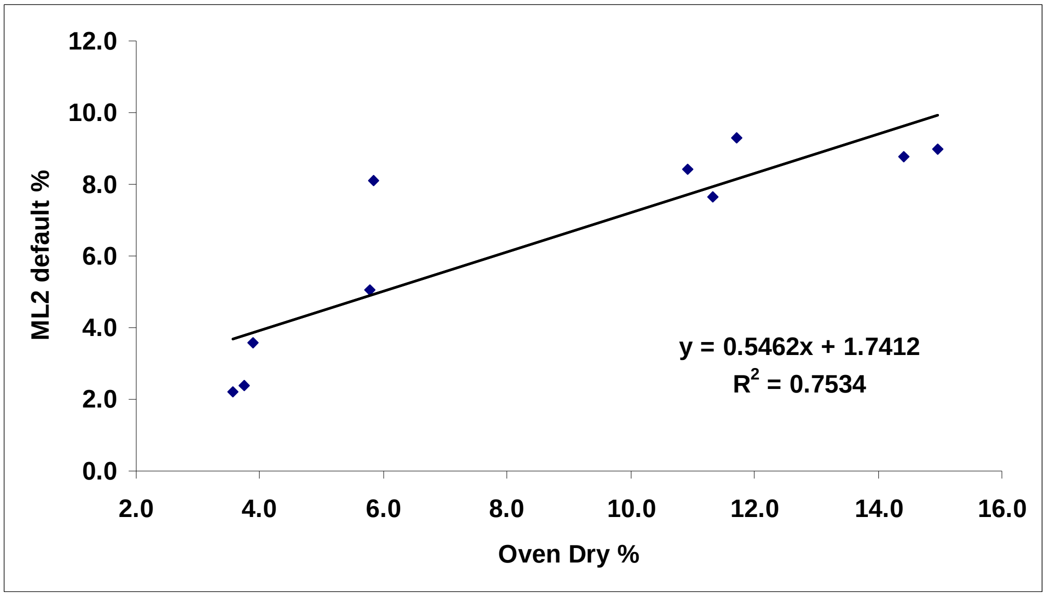
1	2	3	4	5	6	7	8	9	10
	Wilcoxon two-tailed ρ	Sig*	Spearman *r*	One-tailed ρ	Sig*	Oven-dry mean**	ML2 mean**	Mean difference**	N
Fort Bliss default	0.0009	S	0.82	<0.0001	S	10.7	7.8	2.9	15
Fort Bliss calibrated	0.0001	S	0.84	<0.0001	S	10.7	6.5	4.2	15
El Centro default	0.0011	S	0.78	<0.0001	S	7.2	9.5	−2.3	24
El Centro calibrated	0.0075	S	0.78	<0.0001	S	7.2	8.4	−1.3	24
Western default	0.5047	NS	0.71	<0.0001	S	8.5	8.8	−0.3	39
Western calibrated	0.3534	NS	0.69	<0.0001	S	8.5	7.7	0.9	39

* Sig is significance of the relationship. S is significant at a probability of 0.05, and NS is not significant at a probability of 0.05.

** Volumetric soil moisture content in percent.

The Fort Bliss and El Centro default and calibrated ML2 measurements both compare poorly with the oven-dried moisture contents even though correlations are high. However, the mean differences (column 9) may provide additional guidance. The default Fort Bliss and default combined Western site ML2 measurements had smaller mean differences with the oven-dry measurements than the calibrated algorithms. This suggests that the default soil calibration algorithms may be “best.” The exception was that the El Centro calibrated mean difference was somewhat smaller than the default difference. Because all of the mean differences are small for the

default calibrations, the default calibrations would, overall, be the best to use.



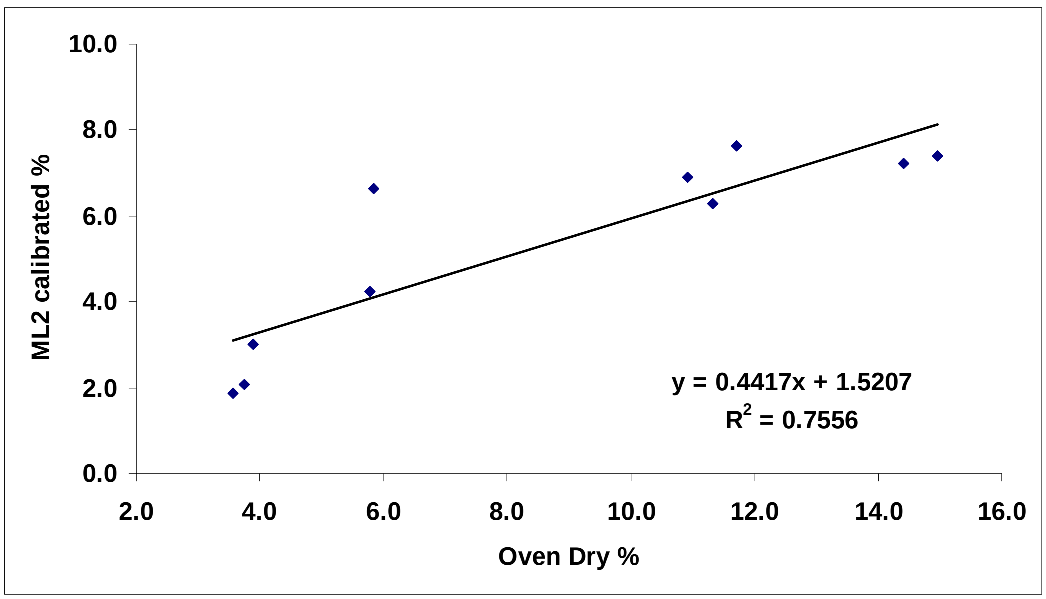
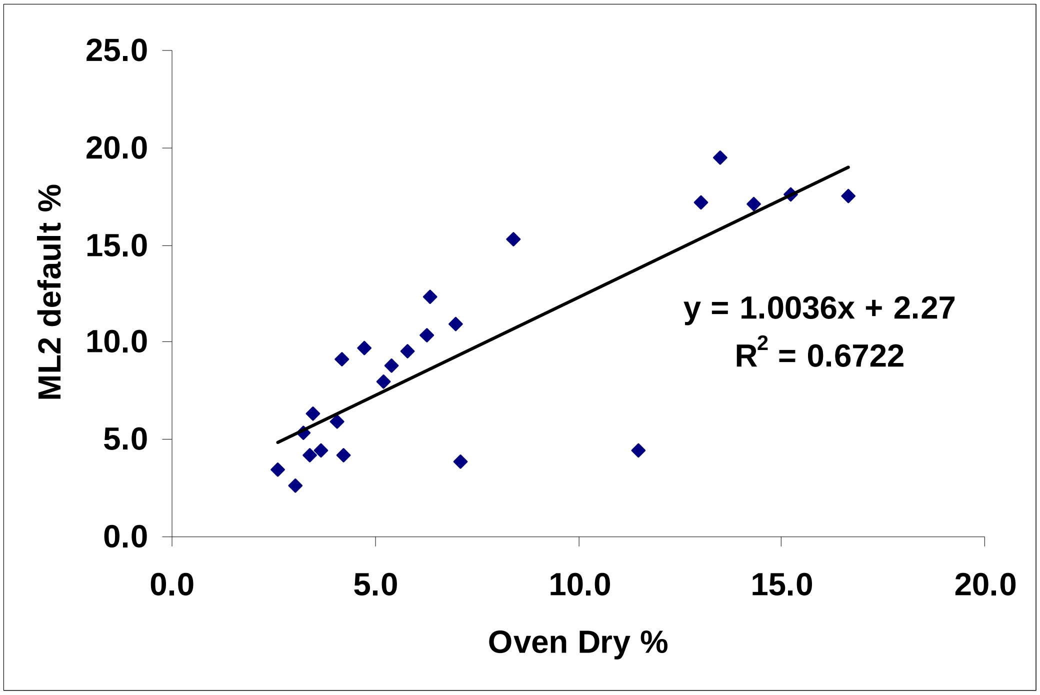


Figure D-12. Scatter plots and Pearson linear regressions for Fort Bliss moisture contents. Oven-dry versus ML2 default calibration (top) and soil-specific calibration (bottom).



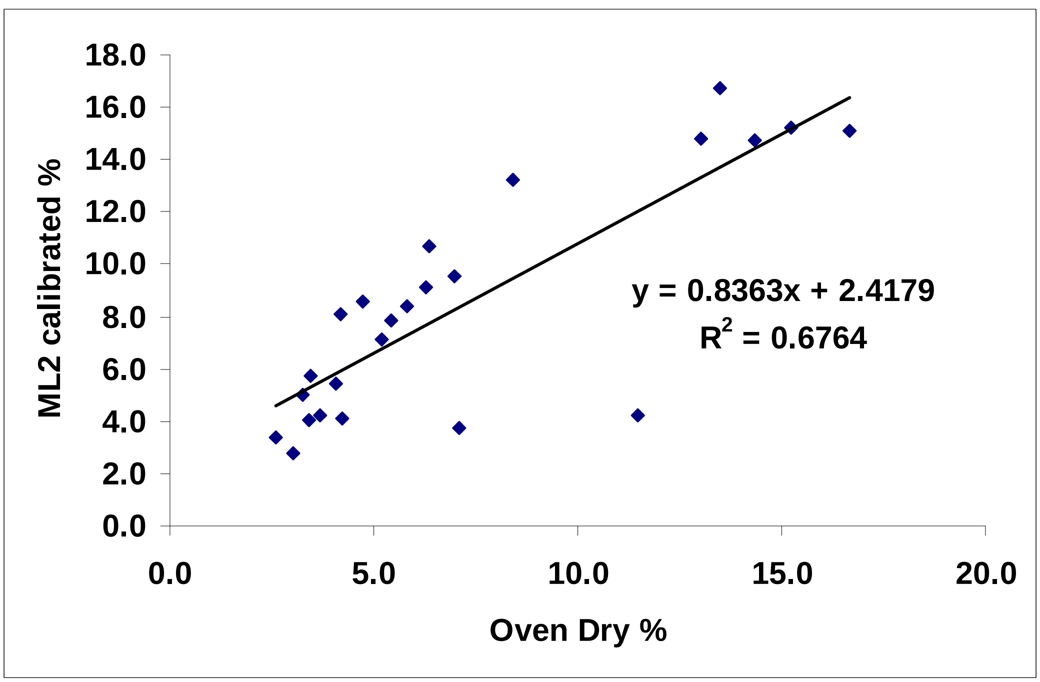


Figure D-13. Scatter plots and Pearson linear regressions for El Centro NAS moisture contents. Oven-dry versus ML2 default calibration (top) and soil-specific calibration (bottom).

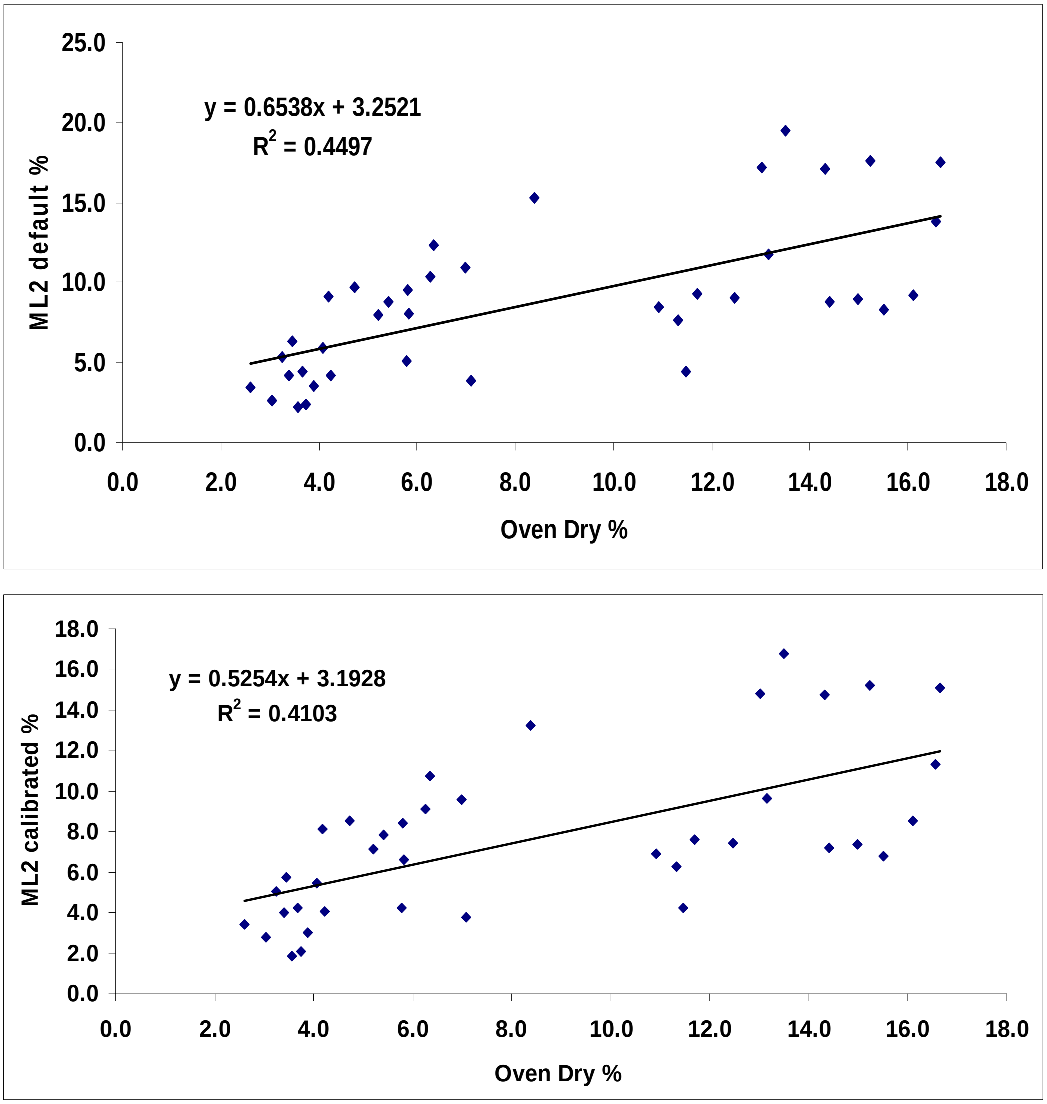


Figure D-14. Scatter plots and Pearson linear regressions for western sites moisture contents. Oven-dry versus ML2 default calibration (top) and soil-specific calibration (bottom).

Summary and recommendations

The purpose of this appendix is to determine which instruments used to measure soil moisture in the OLS field program provide the most accurate measurements for use in soil moisture and soil strength modeling verification work, and for reporting soil moisture to other program partners via field reports and the database archive. This was accomplished by comparing electronic methods used with the potentially more accurate oven-dried moisture contents.

The oven-dry (gravimetric) technique is generally considered the most accurate method for measuring soil moisture content (Rollings and Rollings

1995; Rollings 2006). Oven-dried gravimetric measurements are the most direct method of measuring soil moisture and, other than sampling error, which affects all methods, has the least opportunity for error if careful laboratory methods are followed. The field gravimetric readings, therefore, were accepted as the standard to which electronic methods were compared.

The Troxler nuclear gauge is also a source of soil moisture measurements that is considered acceptable, especially if it compares well to oven-dry gravimetric measurements. However, we did not focus on the Troxler in this analysis because relatively few Troxler measurements were made. The most important interest was to assess the accuracy of the Dynamax electronic instruments, especially the ML2, because they were used to make the majority of moisture measurements that define spatial and temporal changes in OLS soil moisture content.

Because capability was provided by Dynamax for calibrating the PR1, PR2, and ML2 probes to specific soils, and because sufficient soil samples were brought to CRREL from the field, each electronic instrument model was calibrated to the four RAS soils. Then, selected cases where physical soil samples were taken in the field for laboratory oven-dry gravimetric analyses, and electronic (always ML2) measurements taken immediately before or after in the same vicinity (within 1 m), were compared statistically.

Unfortunately, the results of the statistical analysis were not defining. Correlations were weak for the Indiana soils. However, oven-dry gravimetric measurements generally, but not typically significantly, compared best to ML2 measurements made with the default Dynamax calibration. Therefore, best practice is to use the ML2 default measurements when working with the Indiana soil moisture measurements.

Correlations at the western sites were much larger than at the eastern sites, and the relationships were positive. However, the Wilcoxon test indicated that differences in the means of the ML2 and oven-dry measurements were still too large at Fort Bliss and El Centro for the samples to have been taken from the same population. However, when the two sites were grouped, both the default and calibrated ML2 values compared well with the oven-dry measurements.

The lack of discrimination in the statistical analysis leaves only one other value to assess, and that is the absolute difference in means between the ML2 and oven-dry gravimetric measurements. Comparisons suggest that, with a few exceptions, the default calibrations for mineral soils provided by Dynamax performed marginally better than the soil-specific calibrations. Mean differences between the gravimetric and default measurements all fall within the ±5% effective measurement error that Dynamax exemplifies in its literature (Delta-T Devices 1999). Therefore, the default Dynamax ML2 calibrations provide answers, in general, that are closest in magnitude to the oven-dry measurements, and also fall within the effective error range suggested by the manufacturer. Although there is no compelling reason not to use the default Dynamax calibrations for the ML2 instrument at all sites, the values should be used recognizing that comparisons with the oven-dry samples are not typically statistically significant.

With regard to the PR1 and PR2 probes, statistical comparisons with oven-dry measurements were not possible because no oven-dried samples were taken near these probes. However, the soil-specific calibrations did show reduced error for measurements in the column soil at a moisture content of 15%, when compared to the default calibration. This one comparison suggests that PR1 and PR2 performance may be more accurate using the soil-specific calibrations. However, the comparisons are limited in number and moisture content range and were not made in in situ field soils, and the calibration soil moisture was only estimated and not taken from oven-dried measurements. Therefore, it would be prudent not to use the PR1 and PR2 measurements as absolute values, but to use them only for guidance to assess trends and to identify major wetting or drying events.

References

Delta-T Devices (1999) *Theta probe soil moisture sensor user manual Type ML2x*. Cambridge, UK: Delta-T Devices.

Delta-T Devices (2001) *User manual for the profile probe Type PR1*. Cambridge, UK: Delta-T Devices.

Delta-T Devices (2004) *User manual for the profile robe Type PR2*. Cambridge, UK: Delta-T Devices.

GraphPad (1995) *InStat version 3.00 for Windows 95*. San Diego, CA: GraphPad Software. www.graphpad.com.

Myers, R. (2006) Personal communication, November 16, 2006. Research Triangle Park, NC: Troxler Electronic Laboratories, Inc.

Rollings, M. P. and R. S. Rollings, Jr. (1996) *Geotechnical materials in construction*. New York: McGraw-Hill.

Rollings, R. S. Jr. (2006) Personal communication, Rollings Consulting, LLC. Beaufort, SC. November 14, 2006.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
November 2008

2. REPORT TYPE
Technical Report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Opportune Landing Site Program: Opportune Landing Site Southeastern Indiana Field Data Collection and Assessment

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Lynette A. Barna, Charles C. Ryerson, and Rosa T. Affleck

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, NH 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CRREL TR-08-22

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Air Force Research Laboratory Air Vehicles Directorate

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Effectiveness in modern warfare demands rapid, lethal, and stealthy response to a wide variety of adversaries. This requires, in part, the ability to conduct air transport operations to locations where there are no existing runways, and where engineers cannot be prepositioned. One of the most difficult problems is locating large, smooth, flat, and obstruction-free areas that are also sufficiently firm to support at least one aircraft operation, and preferably, many. The opportune landing site (OLS) program utilized existing technologies to rapidly accelerate the process of selecting OLSs using remote sensing technology and state-of-the-ground forecast tools. To evaluate the quality of the OLSs identified, ground truth activities were conducted at four field locations. Two of these sites, described in this report, were located in rural, actively farmed areas in southeastern Indiana. Field measurements were made during four seasons to assess the smoothness, flatness, freedom from obstructions, and, most importantly, the soil strength. The procedures and tools used to assess the candidate OLSs were, to the extent practical, based on established practice for evaluating paved and contingency airfields. The results from the Indiana field activities and the success of the procedures used in assessing the suitability of the OLSs are presented.

15. SUBJECT TERMS
OLS, opportune landing site program, unprepared landing site, satellite imagery, austere airfields, field measurements, in situ soil strength, soil characterization, evaluation

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
U	U	U	U	291	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18